ASTRONOMY

MARCH 1978

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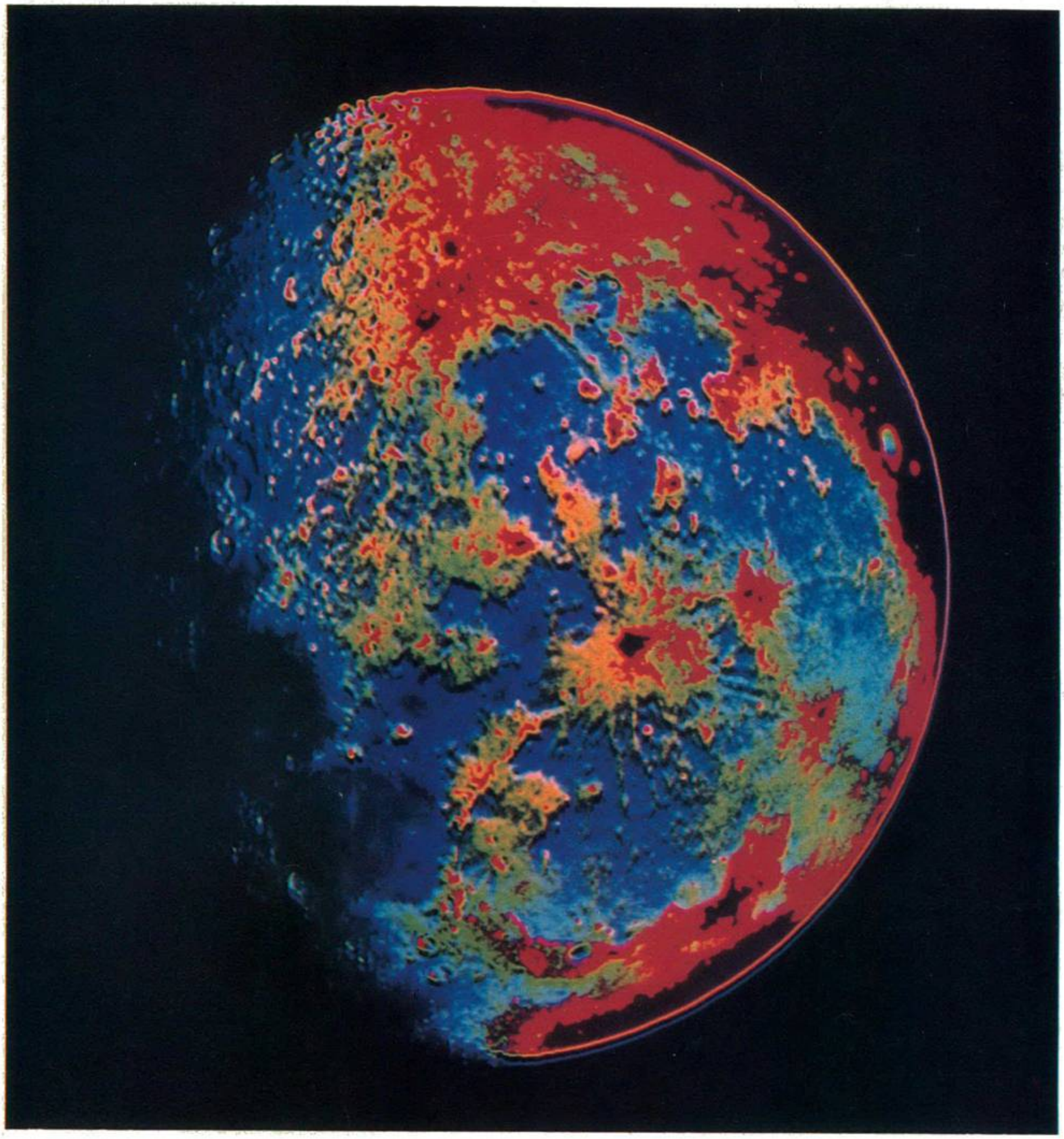
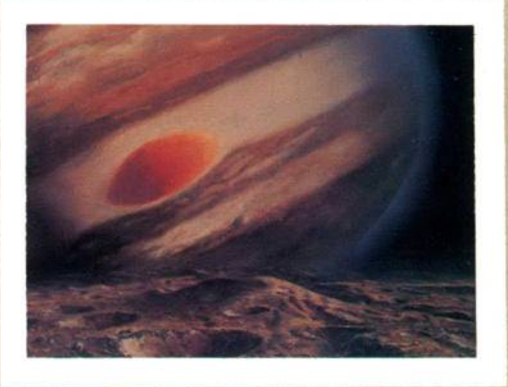


NEW FROM

To you, our readers, ASTRONOMY now offers a series of 8 dynamic, new, full color Art Reprints of some of the best paintings — by artists John Clark, Victor Costanzo, James Hervat, Mark Paternostro, Adolf Schaller and Rick Sternbach — that have appeared in ASTRONOMY Magazine.

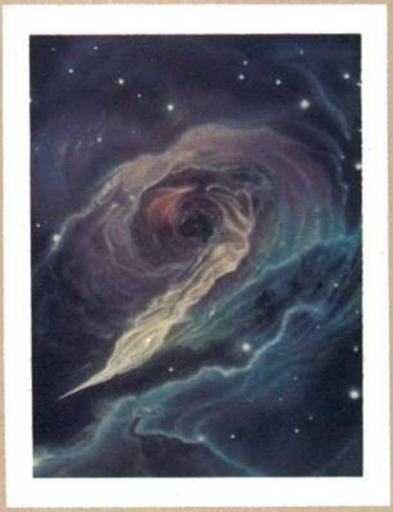
Adding to the drama, depth and realism of each piece, these Art Reprints are printed on 80 lb. linen finish paper, and are coated with a high gloss varnish. And each reprint is surrounded with a one inch white border,



Actual Size: 17" x 22"

Jupiter From Io

This dramatic painting reveals an incredible vista that man may never witness first hand: the incredible bulk of Jupiter looming over the surface of its satellite Io. Located deep within Jupiter's intense magnetic field, Io is one of the most lethal places in the entire solar system. To view this scene, we must rely on the imagination of artist John Clark.



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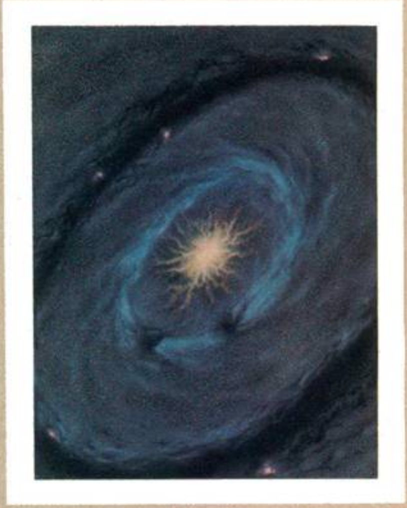
Black Hole

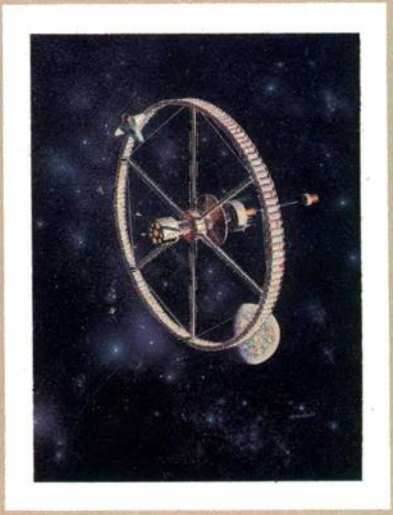
A nearly invisible small black hole speeds through a dense interstellar cloud of gas and dust, leaving behind a trail of gravitationally disturbed material. The infalling material becomes hot and emits light as it drains out of the known universe. Artist Mark Paternostro speculates on the appearance of these still undetected objects.



Actual Size: 17" x 22"

The Galactic Core

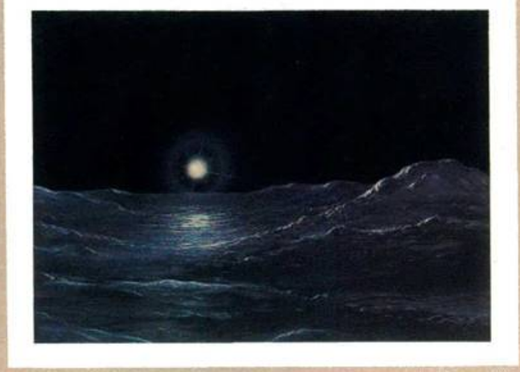
The nucleus of our galaxy is one of the true unknowns in our universe. Recent radio and infrared observations suggest that two titanic swirling rings of gas and dust occupy the core of our galaxy. These rings were apparently produced by an explosion 10 million years ago. Victor Costanzo's painting indicates that actual conditions at the galaxy's center remain a mystery.



Actual Size: 17" x 22"

Colony in Space

What will space stations and orbiting colonies of the future look like? Artist Rick Sternbach provides an ingenious answer in his painting of a mile wide space station wheeling slowly above the gibbous Earth. Shuttle rockets near the station's hub bring ore from the lunar surface for refinement in the station's zero gravity manufacturing center.



Actual Size: 17" x 22"

Pluto

The setting sun glints off a low plain of methane ice on the surface of the smallest and most distant planet, Pluto. The cold and forbidding scene — completely alien to Earth dwellers — comes to life in this rendition by James Hervat. The mysteries of Pluto are brought home to us as we stand and gaze back toward our incredibly distant sun.

ASTRONOMY

making it easier to frame, or suitable for hanging as is.

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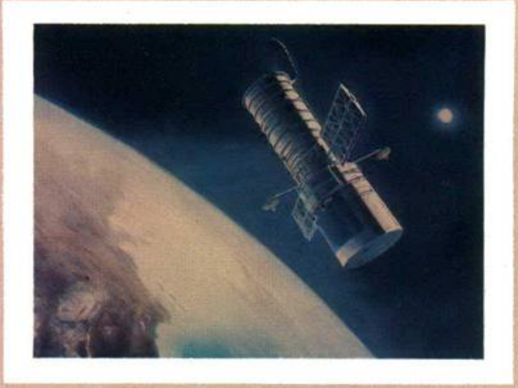

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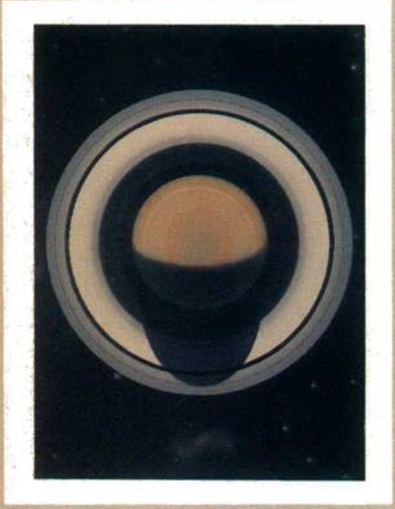
Space Telescope

Painted by John Clark from official NASA blueprints, this poster depicts the Space Telescope — a powerful 94 inch (2.4 meter) aperture telescope due to be launched during the early 1980s by NASA's Space Shuttle. This is an accurate depiction of an instrument that will revolutionize man's view of the universe during the decades it remains in operation.



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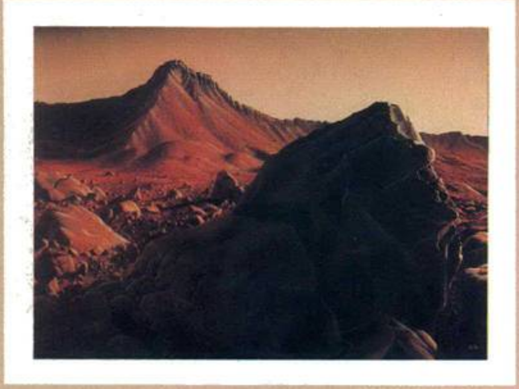
Saturn

In an unusual perspective from above the north pole of Saturn, we can identify the planet's three main rings and their sizes relative to Saturn itself, enabling us to grasp the vast extent of Saturn's ring system. This remarkable painting by Adolf Schaller gives us a view of the planet not obtainable from Earth.

Vallis Marineris

Photographs returned from Mariner and Viking probes revealed for the first time the immensity of Vallis Marineris, the equatorial canyon of Mars. This painting by Adolf Schaller — meticulously transcribed from overhead Viking photos — takes us to the foot of a blanket of landslide rubble in the canyon itself.



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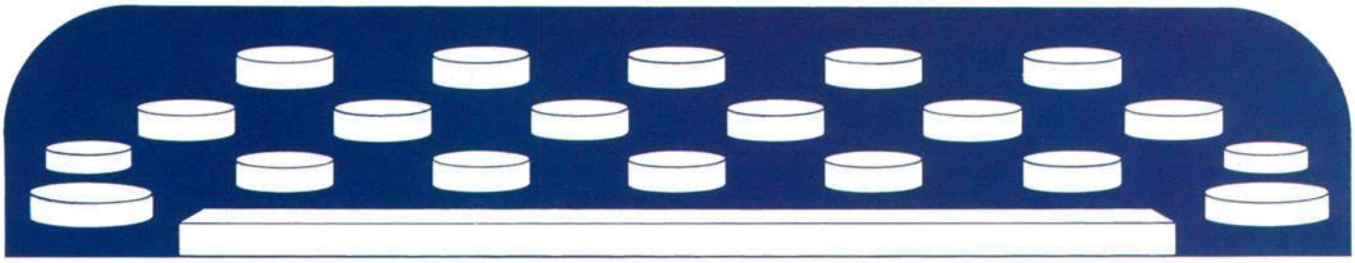

IN FOCUS

Sirs / The statements made on page 10 of the November 1977 issue of ASTRONOMY do not represent the true picture of the search for planetary companions to nearby stars. The long range astrometric program with the Sproul 61cm long focus refractor to search for invisible companions (stellar or planetary) to stars brighter than 12th magnitude and distances within some 25 light-years was initiated four decades ago by Peter van de Kamp. This program is still in progress; the plate collection represents the greatest accumulation of astrometric photographs of nearby stars in the world. Meticulous care has been taken in monitoring the technique to insure homogeneity in the plate data so that for at least the last 25 years the observations are on one system. The modern two-coordinate measuring machine has significantly raised the level of accuracy of data retrieval from the Sproul plates. Three stars on the program which have given indications of substellar planetlike companions continue to be under intensive surveillance. A number of very low mass unseen stellar companions have been discovered, and the star of lowest known mass was determined from this program.

SARAH LEE LIPPINCOTT
Director, Sproul Observatory
Swarthmore, Penn.

Sir / In the November 1977 issue of ASTRONOMY (boxed item on "Allegheny Observatory"), we eluded to a unique program now in its third year. It is a concentrated astrometric survey of a selected number of ostensibly single stars and seeks to determine if any are accompanied by Jovian type planets (i.e., similar in mass and orbital period to Jupiter). The effort is producing annual positions for 27 stars with proven statistical weights more than four times as high as those obtained in any previous study of these objects. Considerable effort is also being expended in the development of more precise observing and reduction techniques. This is the first such *survey* of this nature.

We had no intention of overlooking the efforts of other observatories. In particular, we apologize for not having noted the well-known efforts of our colleagues at Sproul Observatory.

GEORGE GATEWOOD and JOHN STEIN
Allegheny Observatory
Pittsburgh, Penn.

Sir / Regarding "An Astronomer's Life Is Never Dull" (November, 1977), I am often amused at some observatories' public literature (particularly from Hale Observatories) which describe the rigors endured by professional astronomers ("temperatures sometimes below freezing . . ." which "sometimes drop as low as 10 degrees below zero!"). I vividly recall one stretch of observing last winter when I would wait for a night when it "warmed up" to zero degrees before I would even bother to roll out my portable 12.5 inch f/8 reflector! Even on nights like those, I couldn't tarry long at the eyepiece since the lens would fog up just from body heat!

Admittedly, there aren't many as devoted (loony?) as I am when it comes to observing. But to me, my breath still can be taken away simply by stargazing and contemplating the cosmos as easily as it can be by -40 degree Fahrenheit wind chills.

GREG GONIA
West Allis, Wisc.

Mr. Gonia / Don't forget the Canadian observers living in Alberta, Saskatchewan and Quebec, where actual temperatures may fall to -30 to -50 degrees Fahrenheit on clear nights!

Sir / After many years of observing, I now am planning to photograph what I observe. After reading Richard Berry's article on darkrooms (June 1976) I have some questions.

Is *all* the photographic paper used in astrophotography blue sensitive — and why? Are there any that aren't?

Also, after learning everything I thought there was to know about equatorial mounts, I am suddenly faced with declination slow motion. Just what is this?

GARY L. MCMILLS
Houma, La.

Mr. McMills / Photographic paper is blue sensitive for two reasons. First, the simplest photographic emulsions are naturally sensitive to blue and ultraviolet light only; yellow and red sensitivity has to be added by using dyes in the manufacture of the paper. Second, in a darkroom you can use yellow light to work by and inspect the pictures as you develop them, so photographers consider ortho (blue only, that is) sensitivity an advantage. Special papers for making prints from color negatives are available — Kodak's trade name is Panalure.

The declination slow motion is simply a fine adjustment device so you can move the telescope a tiny amount to correct for tracking errors if the telescope is not perfectly aligned on the pole. If you are making short exposures, you won't need one.

Sir / In your article, "Tunguska: Collision With A Comet" (December 1977), why do you show a drawing of a comet heading toward the sun when it is stated that the comet is heading away from the sun?

If the comet hit Earth while it was heading away from the sun, the comet tail would have preceded the comet head. Would the results of a tail-on collision be contrary to the comet theory for the Tunguska blast?

MICHAEL A. STEGALL
Jackson, Miss.

Mr. Stegall / We show the comet to the far side of Earth, moving away from the sun before the collision with Earth. We chose this point in time, as well as an unusual viewpoint looking steeply toward the sun, because it permitted us to do a very dramatic painting. To a person on Earth shown in this painting, the comet and the sun would be close in the sky, with the comet all but invisible. Since the tail of a comet is quite insubstantial, it doesn't matter whether the comet hit head or tail first.

Ooops!

Here are a few errors that have appeared in recent issues:

January 1978, page 50 — in "Building A 6" Reflector, Part 5", a layout change made too late to correct the text caused the promised diagram, showing the hand tracking unit, to be omitted — probably confusing hundreds of readers! We'll run this diagram with an explanation of it in an upcoming issue.

January 1978, page 27 — Alex York points out that his photographs show prominences, not Baily's Beads, and that the ship he sailed on was the Fairsea, not the Fairwind.

ASTRONOMY

The World's Most Beautiful Astronomy Magazine

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Cover

Color can highlight differences in shading in your astronomical pictures. On ASTRONOMY's cover this month, our familiar moon takes on a brilliant new appearance: The lunar "seas" are blue, and the mountains and highlands bright red. You can enhance your own astrophotographs if you follow the techniques described in Photography in Astronomy. This month, travel with us as we explore distant clusters of stars; then follow us as we investigate the strange cosmologies that compete with the big bang. Find out what's inside your telescope in Equipment Atlas, and learn the spring constellations. While you're at it, this month you'll have a chance to view all five bright planets! Photograph by Fred Espenak.

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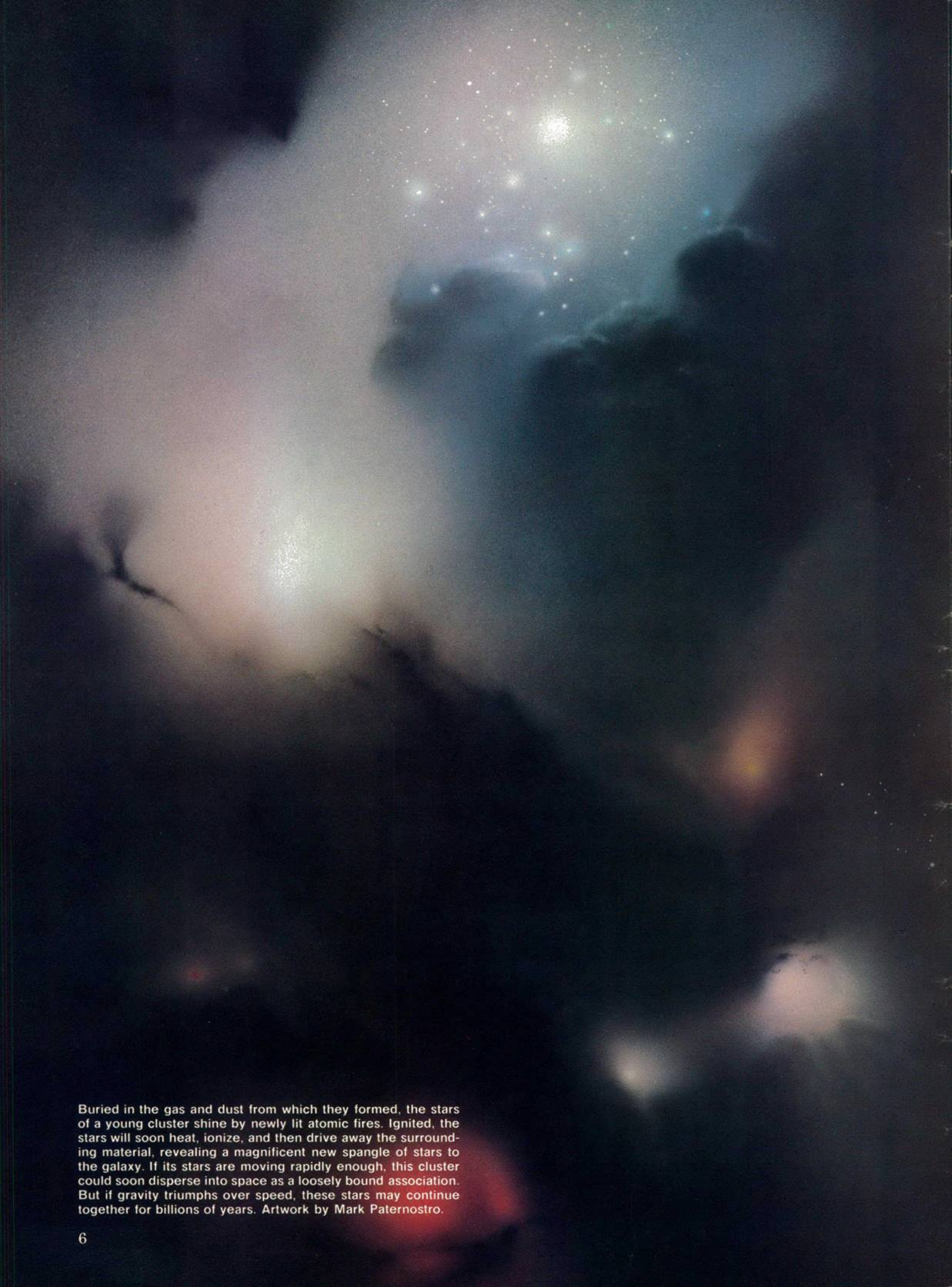
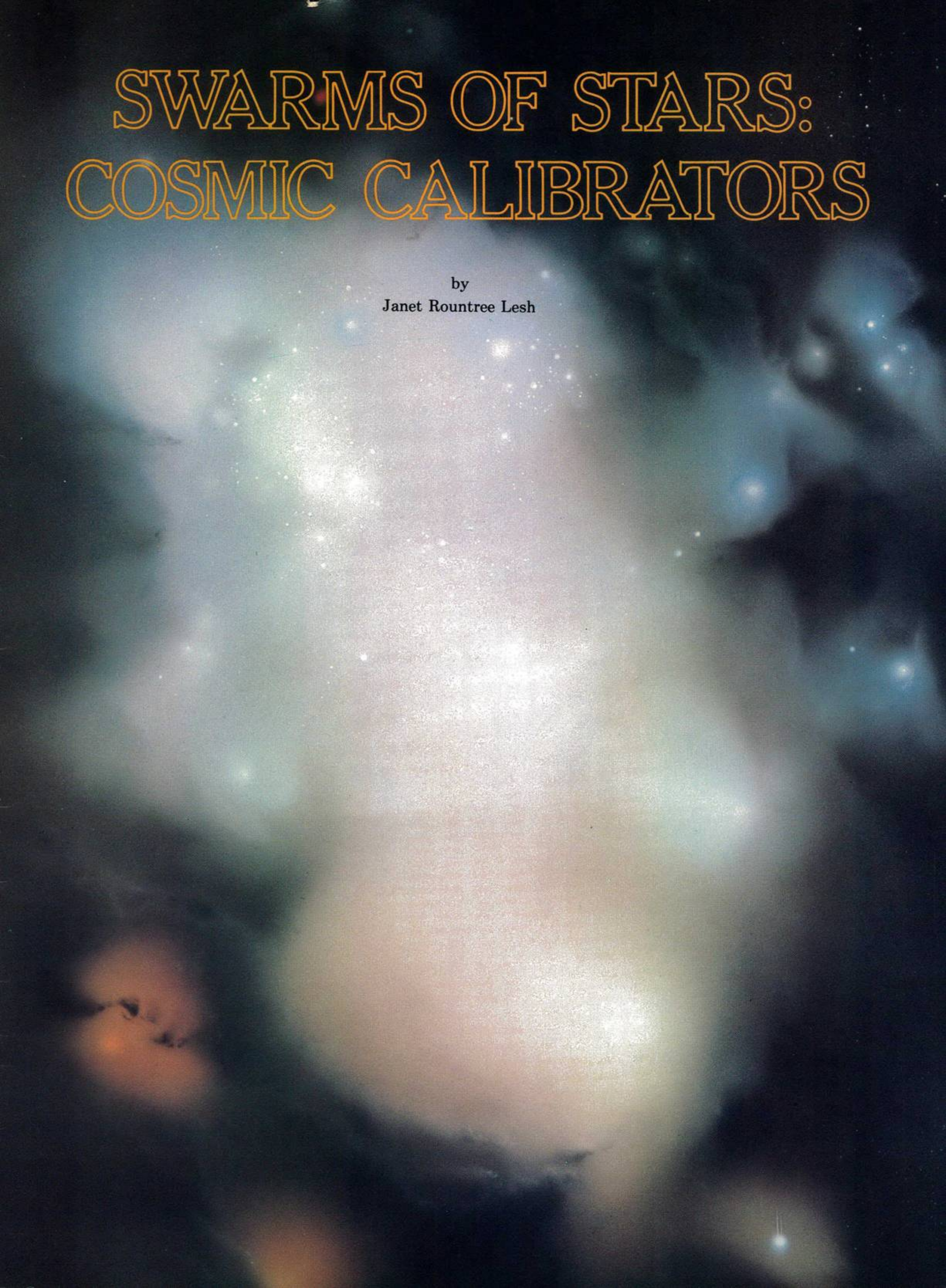
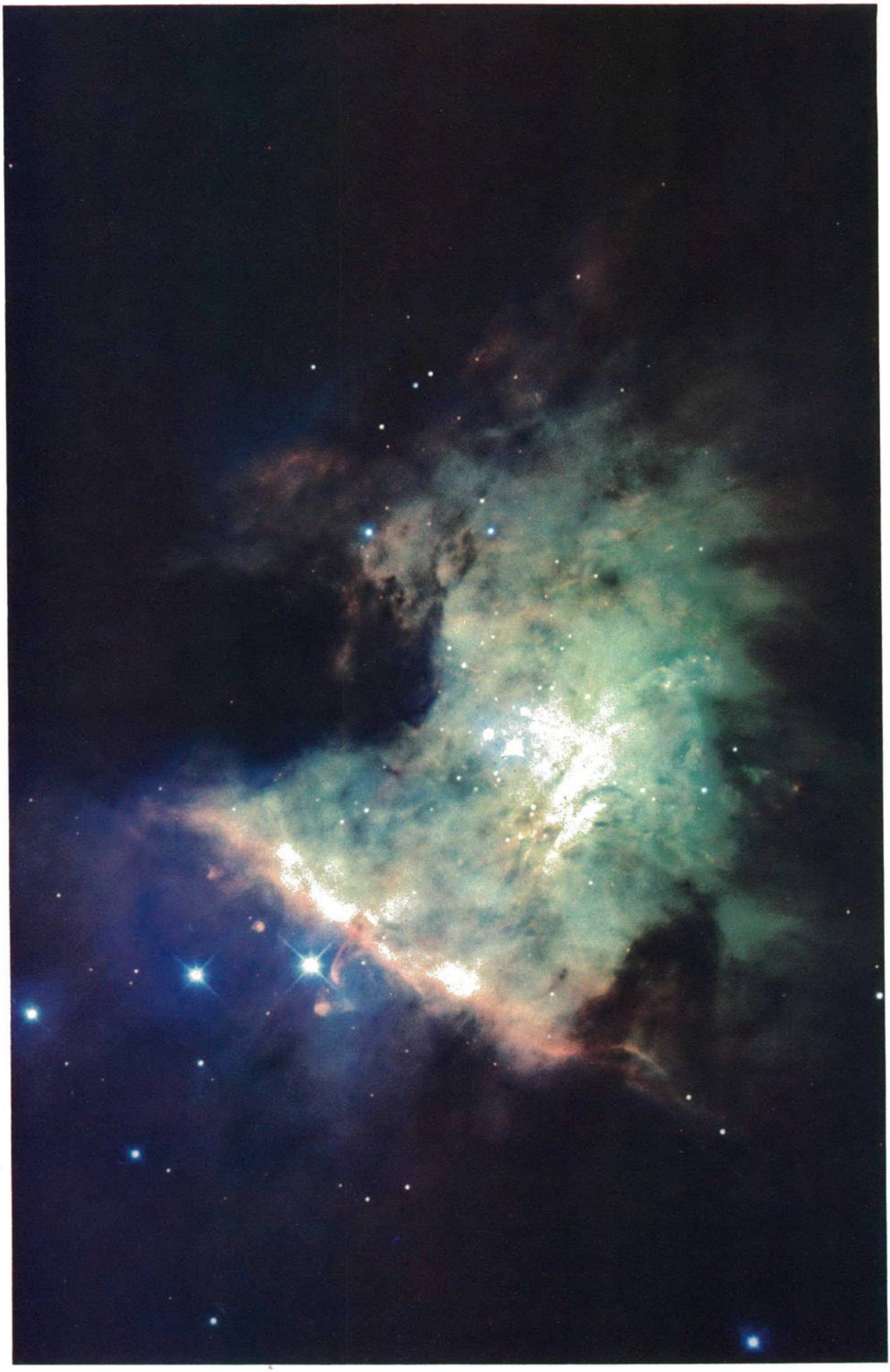


Buried in the gas and dust from which they formed, the stars of a young cluster shine by newly lit atomic fires. Ignited, the stars will soon heat, ionize, and then drive away the surrounding material, revealing a magnificent new spangle of stars to the galaxy. If its stars are moving rapidly enough, this cluster could soon disperse into space as a loosely bound association. But if gravity triumphs over speed, these stars may continue together for billions of years. Artwork by Mark Paternostro.

SWARMS OF STARS: COSMIC CALIBRATORS

by
Janet Rountree Lesh





The sun whizzes along on its path around the center of the galaxy unaccompanied (so far as we know) by anything except our own solar system. No binary companion revolves about it, and the nearest star, four light-years away, is not even a close relative. But many stars do not lead such a lonely existence — they travel in small, closely knit groups called galactic *clusters*. In such clusters all the stars follow nearly parallel paths in space. Other stars travel in large, loosely connected *associations*, whose members are flying apart! Why should stars behave this way? Why aren't they loners like our sun? Stars travel in crowds because most stellar births are *multiple* births, yielding many stars having the same age and sharing the same initial motion — that of the interstellar cloud from which they were formed. It's obvious, then, that astronomers are interested in star clusters because they tell much about how and where stars are born, as well as how they age and evolve. Not so obvious — but very important to astronomy — is that clusters provide a yardstick for measuring distances in space which are necessary for measuring the size and structure of our Milky Way galaxy.

First, though, just what are clusters? *Galactic* clusters are fairly amorphous congregations of stars held together by their mutual gravitational attraction. They contain a few to several hundred members, packed into a volume whose typical dimension is around 25 light-years. They are found in the spiral arms of our galaxy, often associated with interstellar matter. Galactic clusters differ from *globular* clusters, which are rich, spherical balls of 100,000 or so stars. While most globulars circle around outside the plane of our galaxy, galactic clusters are right in the plane. Around 1,000 galactic clusters have been observed, but lots more are probably hidden by dark interstellar clouds; indeed, there may be as many as 10,000 to 100,000 such clusters in our galaxy.

But one cluster — which we know as the Hyades — stands out from all the rest. This cluster is the basis for the entire astronomical distance scale in our galaxy; it is the foundation for measuring distances to other galaxies, and ultimately for the age and distance scale of the universe.

Distances are not mere numbers; learning astronomical distance is fundamental in finding out what astronomical objects are and how they got there. To understand why the Hyades cluster is so important, imagine how a group of stars moving on parallel paths looks from the perspective of a moving Earth. As we all know from having seen railroad tracks or telephone wires recede into the distance, perspective causes parallel lines to appear to converge at infinity. So when we look at a moving cluster of stars — whose motion in space is parallel — their paths must appear to meet at a point in the sky. If the cluster is approaching us, the stars appear to radiate out from a distant point in the direction from which the cluster is coming; if the cluster is moving away from us, the stars appear to converge toward the direction in which the cluster is moving. We find the "convergent point" by drawing arrows to represent the apparent motion of each star, and prolonging them until they meet. Once the direction of a star's motion in space is known, we can combine this information with the star's *radial velocity* (line-of-sight motion) and *proper motion* (apparent movement across the sky) to get its distance. In this way we find the distance of each individual star in a cluster, and finally the average

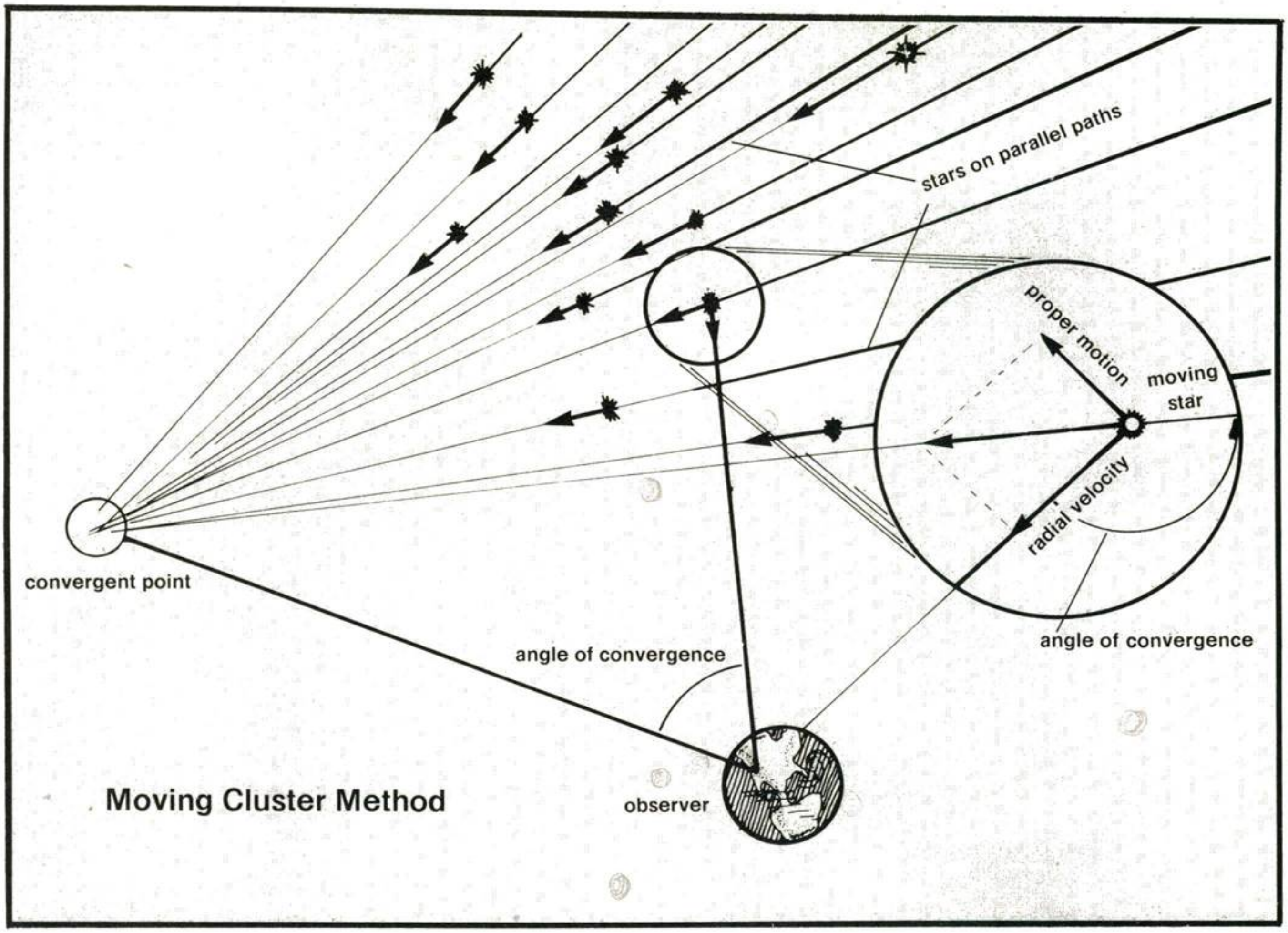
If you look deep into the heart of the Orion nebula, you'll find a cluster of stars as well as the famous Trapezium group. Buried in dust and gas, and still too young to shine in visible light, is a far richer invisible cluster of stars shining brightly in infrared radiation. The nebula itself shines because the stars embedded in it heat it and strip the electrons from its atoms. As the electrons recombine with other atoms, they emit light, much as atoms do in a neon sign. Lick Observatory photograph.

Naked Eye Clusters

The most famous cluster is undoubtedly the Pleiades, which is mentioned in the Bible and the writings of Homer, as well as in other ancient sources. It is one of the most striking objects in the winter sky, located in the constellation Taurus at the bull's shoulder.

In Greek mythology, the Pleiades were the seven daughters (Alcyone, Maia, Electra, Merope, Taygete, Celaeno and Asterope) of Atlas and Pleione; pursued by the hunter Orion, they were given refuge in the sky. Only six stars in the Pleiades are now clearly visible to the naked eye, although dozens can be seen through a pair of binoculars, and hundreds through a telescope. The fact that seven maidens are described in Greek and other ancient legends, while most people can see only six stars today, has given rise to many theories, both mythical and scientific, to account for the "lost Pleiad". Of course, it's possible that one of the stars was a little brighter in the past than it is now. But more likely the mystical significance of the number seven prompted legendmakers to invent tales involving seven original stars, of which one was later "lost".

Near the Pleiades in the winter sky is the Hyades cluster, an apparently triangular group of stars that makes up the face of Taurus the bull. Five of the Hyades are visible to the naked eye (in Greek mythology, they represented the five half-sisters of the Pleiades), but a telescope reveals several hundred. When the Pleiades and Hyades rose with the dawn in ancient time, farmers knew it was time to plant crops, because the spring rains were at hand. The name Hyades actually means "rainy ones".



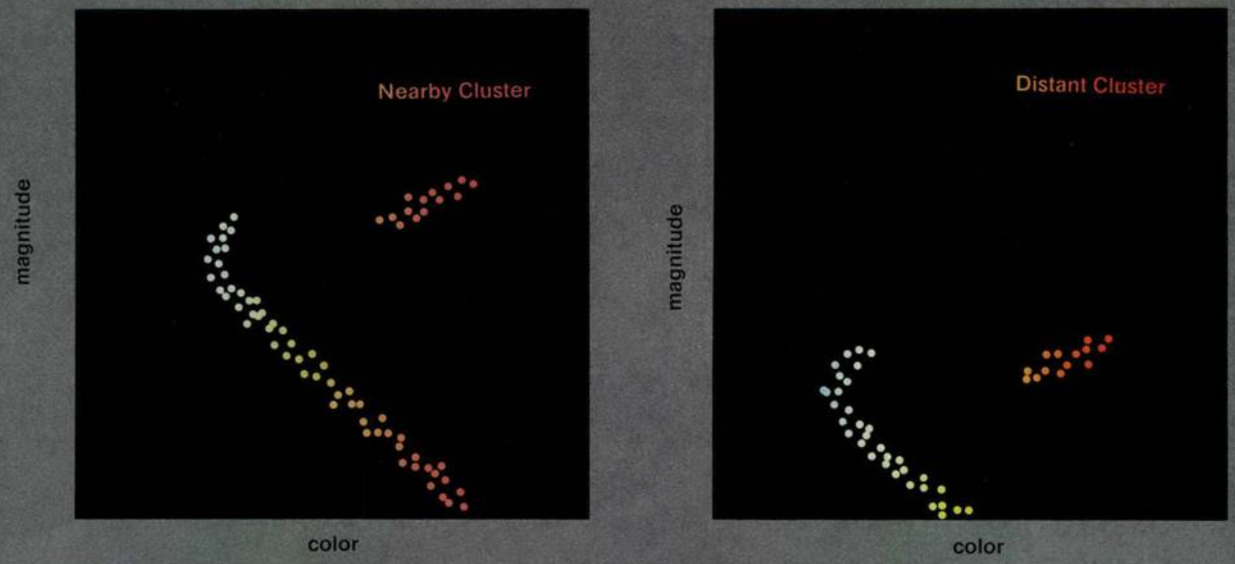
distance of the cluster as a whole (see illustration above).

Other than *trigonometric parallax* (a method of distance determination based on the reflection of Earth's orbital motion) and a few other devices that work only in special cases, the so-called "moving cluster method" is the only way astronomers have to find distances to individual stars without making assumptions about their intrinsic brightnesses. But the moving cluster method works only for the very nearest groups of stars; if a cluster is too far away, its proper motions can't be measured accurately enough to yield a good convergent point. Among our nearby clusters, only the Hyades (about 150 light-years from the sun) has enough members to define a really good sequence of stars for comparison with other clusters. Thus the Hyades, fortuitously both near and rich enough, has become the cornerstone of the entire galactic distance scale.

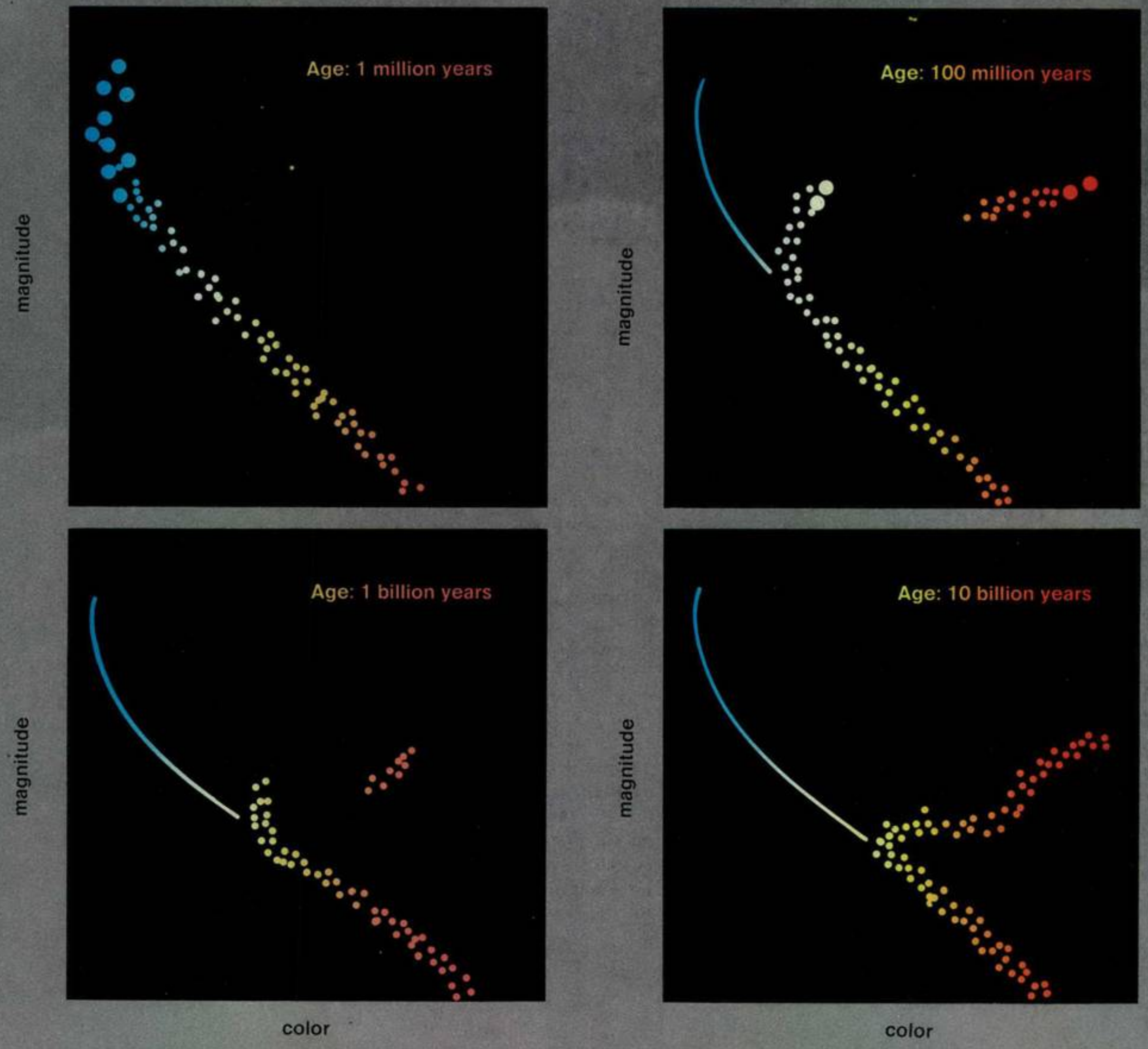
Extending the distance scale deeper into space relies on the simple fact that stars in a cluster have almost exactly the same distance and very nearly the same age. When the apparent brightness of stars in a cluster is plotted against their color (in a color-magnitude diagram similar to a Hertzsprung-Russell diagram), most the points lie along a *main sequence* like the one defined by stars near our sun. The Hyades form such a sequence, and so do the Pleiades and other clusters. When a cluster is farther away than the Hyades, its stars will appear fainter; thus on its color-magnitude diagram, the main sequence will parallel that of the Hyades — but at a fainter magnitude. The amount by which the main sequence of the second cluster (at an unknown distance) must be moved to match the Hyades main sequence (whose distance has been painstakingly measured, as we've already seen) is a measure of how distant the second cluster is. In other words, since we already know the distance to the Hyades, we can find the distance to the second cluster; it, in turn, can then be used as a main sequence standard for comparison with still other clusters. The first cluster to be matched with the Hyades is the Pleiades, about 400 light-years from the sun. Even more distant is the double cluster in Perseus, at over 5,000 light-years. Distances to many of the clusters in our galaxy have been found this way.

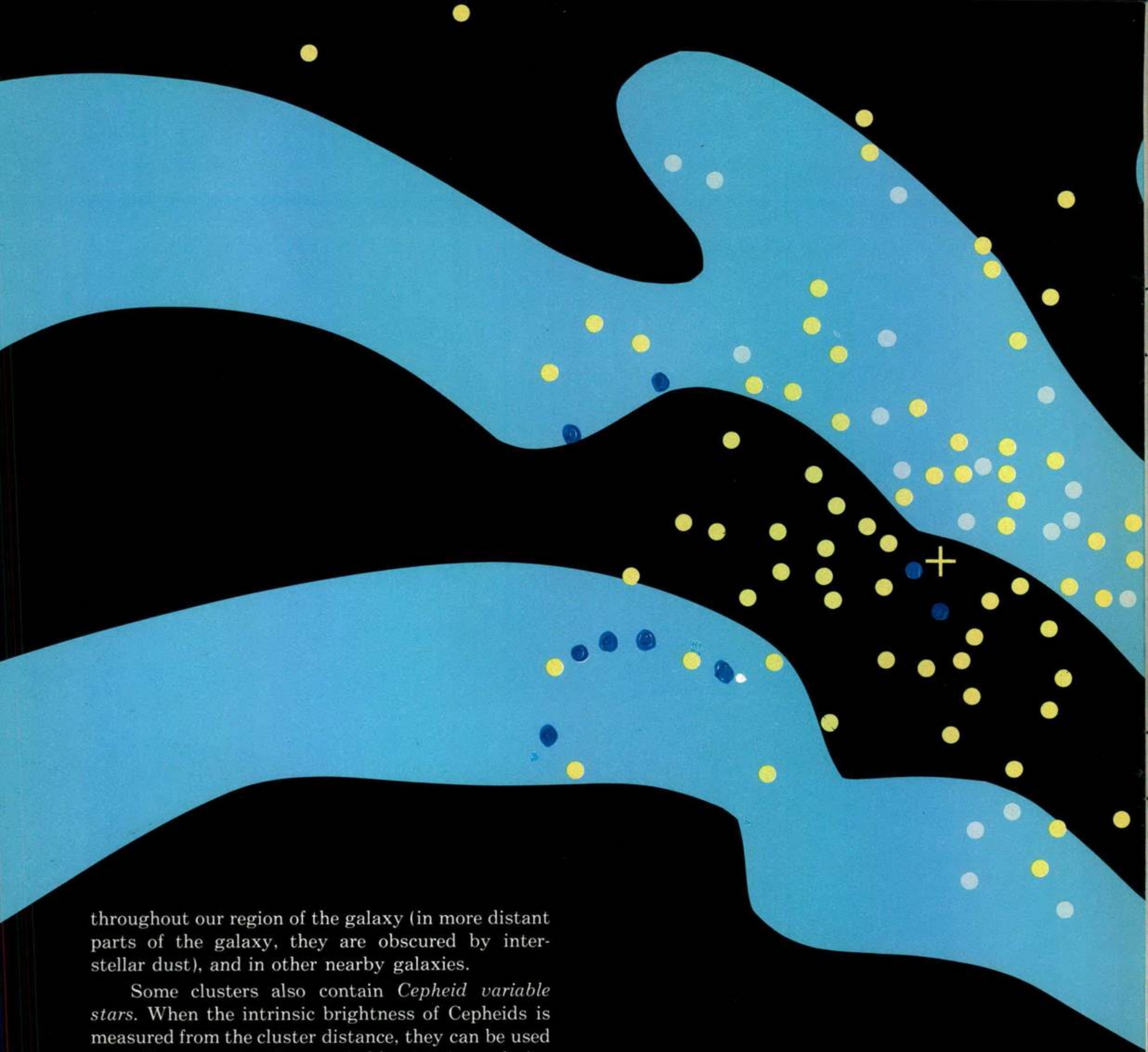
Once astronomers have the distance to a galactic cluster, the *intrinsic brightness* — how bright it actually is — of all the objects in it is known from a comparison with the apparent brightness that astronomers can measure directly. Now, the Hyades cluster does not contain any very bright stars or any variable stars, but other clusters do contain very useful bright blue supergiants. Even when the main sequence is too faint to observe, the blue supergiants shine — acting as "standard candles"

Color Magnitude Diagram



Evolution of a Cluster





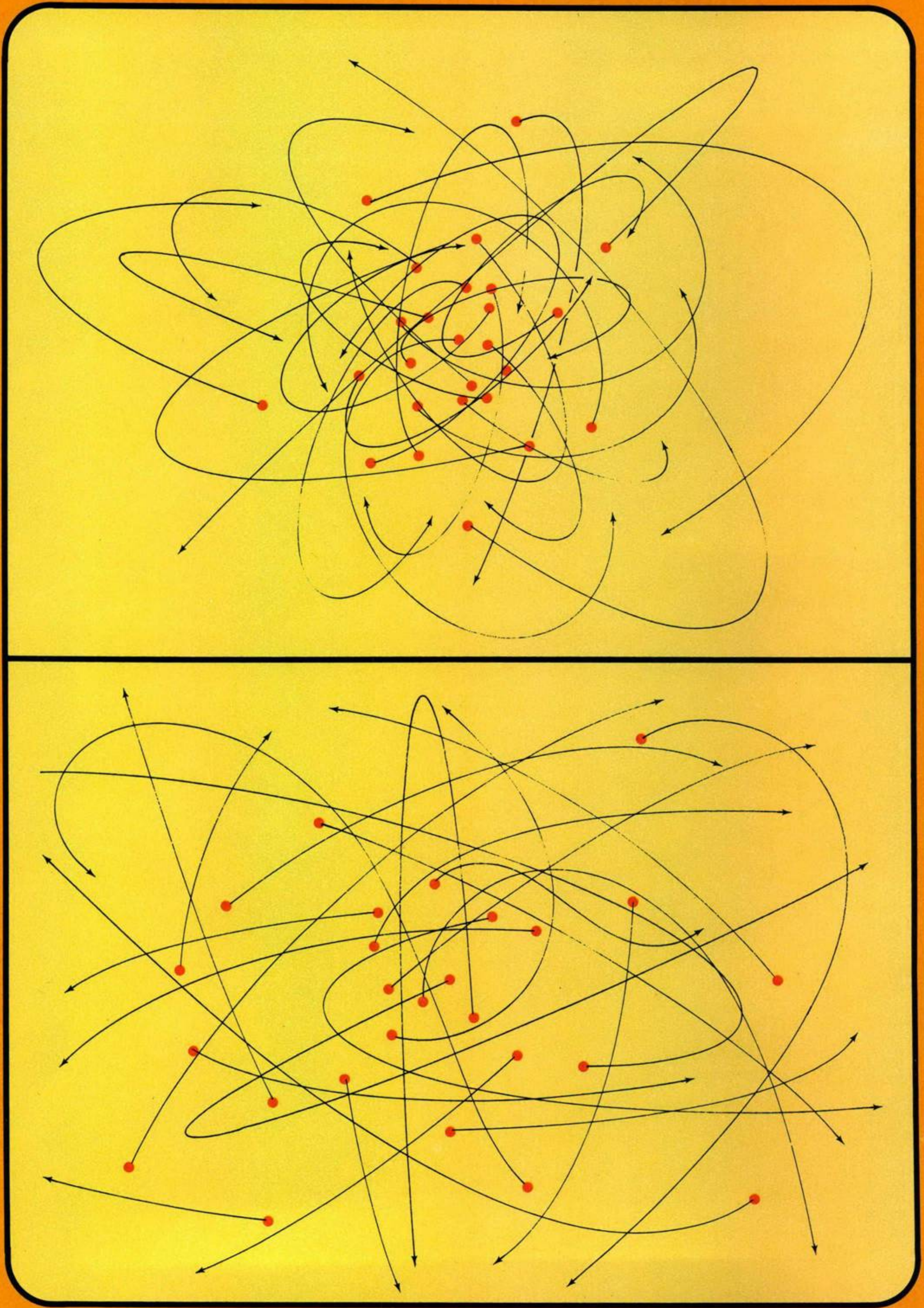
Clusters form in the spiral arms of our galaxy and then, via their random motions, disperse throughout the disk of the galaxy. The spiral arms — as defined by dust, gas and other "spiral arm tracers" — are outlined in dark blue. Superimposed are the youngest galactic clusters (shown in blue as a mnemonic for their characteristic young blue stars) and older clusters (shown in yellow). While the young clusters cling to the spiral arms, the older clusters have moved away. The position of the sun is shown by a cross. Diagram by Richard Berry.

throughout our region of the galaxy (in more distant parts of the galaxy, they are obscured by interstellar dust), and in other nearby galaxies.

Some clusters also contain *Cepheid variable stars*. When the intrinsic brightness of Cepheids is measured from the cluster distance, they can be used to calibrate a peculiar *period-luminosity relation* for Cepheids: The brighter a Cepheid variable is, the more slowly it varies! Thereafter, whenever a Cepheid with a certain period is observed in another galaxy, astronomers consult their intrinsic brightness calibration charts and compare the actual brightness with the apparent brightness. This gives *the distance to the other galaxy*.

So cluster distances, based on the moving cluster method for the Hyades and on color-magnitude diagrams for other clusters, are essential for establishing the distance to nearby galaxies. From these, the boot-strapping method continues as the known distances to the nearest galaxies are used to calibrate a relation between the apparent size of a galaxy and its distance. This in turn is used to calibrate the well-known Hubble law relating redshifts to distances. The Hubble relation is the basic yardstick for measuring distances in the universe — and it all goes back to the motion of the Hyades!

Imagine, then, the consternation in astronomical circles when it was suggested, about 10 years ago, that the Hyades cluster is actually about *20 percent* farther away than the moving cluster method indicates. Actually, a number of astronomical



puzzles — such as the difficulty of building "model" stars with the right chemical compositions, colors, masses and luminosities for the Hyades, or the fact that Cepheid variables in clusters appear to be too massive to pulsate with their observed periods — could be solved if the Hyades were somewhat farther away than we originally thought. Photometry and spectroscopy of the Hyades stars also point to a slightly larger distance. The "random errors" — resulting from the inevitable inaccuracy of the observations — of the proper motions that go into the moving cluster distance are really quite small. But the disagreement with other (less basic) distance indicators may mean that the whole proper motion system has a "systematic error" — that is, all proper motions may be too large by a constant amount, for reasons that are still unclear. This is one of the less spectacular but most important questions in modern astronomy, and until it is answered, there will always be doubts about the "real" distance to many celestial objects.

Clusters, then, are useful measuring tools. But what of the clusters themselves — what do we know of them? The color-magnitude diagram of a cluster tells us far more than just the cluster's distance; it also tells how old the cluster is. When a cluster is born, all its stars quickly settle down to the main sequence where they remain for millions of years, converting hydrogen to helium in their deep interiors and radiating away the energy released in the process. But when the hydrogen in the core region near the center of a star runs out, the star begins to change. It moves upward and to the right in the color-magnitude diagram — becoming brighter, and cooler but larger — on its way to becoming a red giant. Massive stars burn hydrogen faster than smaller stars, so they are the first to move away from the main sequence. Since all the stars in a cluster start their main sequence lives at about the same time, the bright blue end of the main sequence (the upper left in the color-magnitude diagram), which contains the most massive stars, disappears first as these stars move off into the red giant domain. As the cluster gets older, the main sequence becomes shorter and shorter, and more and more red giants appear. By looking at the color-magnitude diagram, astronomers set a limit on the age of the cluster: It must be older than the main sequence lifetimes of the stars that have moved off the main sequence, but younger than the main sequence lifetimes of those still on it. In practice, the age of a cluster is usually said to be equal to the main sequence lifetime of the bluest (most massive) star still on the main sequence, which often shows signs of being just ready to leave. The color of this star (or its spectral type) is called the *turn-up point* of the cluster (see the diagrams on page 11).

A cluster of stars and an association differ importantly: A cluster (above) is bound; its component stars do not have enough energy to escape the gravitational well of the group — whereas an association (below) is unbound or loosely bound; stars "evaporate" rapidly until there is nothing left but a loose group of stars traveling together. Associations soon mix with the background stars of the sky and eventually become indistinguishable from the background. Clusters may retain their group identity for billions of years. Diagram by Richard Berry.

Associations seem to play a central role in the formation of massive, early type stars. In fact, *all* the existing O and B stars in the galaxy may have originated in OB associations. Although only about 80 associations are listed in catalogs, many more must be hidden by dark interstellar matter. Several thousand associations probably exist in the galaxy right now. If each lives for an average of 10 million years (before the expansion spreads the stars far out into space, wiping out all traces of their origin), then about a million associations have existed in the history of the galaxy. Assuming that each association produces 100 to 1,000 stars, a total of 100 million to 1 billion stars can be accounted for. This is enough to take in the entire spiral arm population. O and B stars that now appear in the field are probably the products of long dead associations.

The well-known clusters turn out to have very different ages. The double cluster in Perseus follows the main sequence for most of its length (only the most luminous blue stars have left), so it must be very young — perhaps two million years old. The Pleiades cluster is older — some of its stars have evolved away from the main sequence — so it must be about 100 million years old. The all-important Hyades cluster is around one billion years old, so that many of its stars have left the main sequence. Indeed, its brightest stars are red giants.

Although stars of all spectral types from O to M are found in galactic clusters, high luminosity stars are more common than in the solar neighborhood, and dwarfs are much scarcer. Even though some process favors massive, high luminosity stars in clusters, galactic cluster stars are representative of the type of stars found in the spiral arms of galaxies. The chemical elements they contain have nearly the same proportions as in the sun — that is, they are made up of about 90 percent hydrogen atoms, nine percent helium atoms, and one percent "heavier elements". Compared to the stars outside the spiral part of the galaxy, this abundance of heavy elements is fairly high. It shows that the stars in even the oldest galactic cluster are made up of second generation gas or "recycled" material, in which the heavy elements were created by fusion in the early generations of stars, or in supernovae (see "Supernovae!", ASTRONOMY, April 1977).

Besides stars, some clusters contain visible clouds of gas and dust, like the "powder puff" patches of nebulosity associated with the Pleiades, reflecting some of the light from the bright cluster stars. In other young clusters there are masses of cool hydrogen gas that can be detected only with radio telescopes; these hydrogen clouds can extend over three times the optical size of the cluster! Many clusters with bright blue stars also contain globules — small, very dense, dark, apparently spherical regions of absorbing material — once thought to be sites of star formation.

Many types of variable stars also turn up in clusters — the Cepheids that are so useful in measuring distances, eclipsing binary stars, T Tauri stars (which we'll discuss later), flare stars, and a spectacular group called *spectrum variables*. Pleione, a star in the Pleiades, is a spectacular, irregular spectrum variable. From time to time it ejects shells of material into space. The shells have a rich metallic spectrum unlike the underlying star, which shows mainly hydrogen and helium lines. So when a shell is ejected, the spectrum of the star seems to go wild! Because of their unusual behavior, these objects promise future insight into stellar structure.

Because cluster stars are packed into such a small volume, they are bound together by strong gravitational forces. In the center of a rich cluster, the stars may be only 1-1/2 light-years apart, and the density may be 100 times that of the solar neighborhood! In addition to their parallel motion through space, cluster stars also have *random motions* which tend to tear the cluster apart. If the cluster can be assumed to have settled down to a steady state, there is a principle (called the *virial theorem*) from which astronomers calculate how massive the cluster must be for the gravitational force to resist the cluster's being torn apart by random motions. Oddly enough, this calculated mass is usually much greater than the sum of the masses of the stars we see! Since the cluster exists, the "unseen mass" must somehow be present — whether in the form of very faint low mass stars, neutral or molecular gas, or dust. The unseen mass is a perplexing problem to astronomers today!

Unlike clusters, which cling together because of gravitational attraction, *associations* consist of stars that are physically similar and have a common origin, but are too far apart to be gravitationally bound. Spread over volumes 100 to 700 light-years in size, they don't leap to the eye the way clusters do when you're looking through a small telescope. *OB associations* (the most common type) are discovered just by counting the number of bright blue stars that appear to be near each other in space. Typically, associations contain 5 to 50 type O and B stars. OB associations also contain main sequence stars of later spectral type like the sun, but it's hard to distinguish these stars from the surrounding field.

Associations are so big that they aren't held together by gravity. The member stars are flying apart with expansion velocities of about 10 kilometers (6.21 miles) per second. This isn't as bad as

Star clusters and associations are by no means unique to our Milky Way galaxy. They have been found and studied by the hundreds in at least eight nearby galaxies. The Magellanic Clouds, our galaxy's nearest neighbors, contain over 1,000 young clusters — many with bright blue stars and some with Cepheid variables. These clusters are mightier objects than our familiar Pleiades which, if removed to the Magellanic Clouds (200,000 light-years distant), would be an inconspicuous 15th magnitude object. Slight differences in helium and heavy element abundances show up when comparing Milky Way and Magellanic Cloud clusters — a potential nuclear chemistry lesson for astrophysicists studying stellar evolution! About 120 associations have also been seen in the Magellanic Clouds. With a mean diameter of 250 light-years, they are somewhat larger and richer than those in the Milky Way.

The Andromeda nebula (M-31), our galaxy's "twin", is also a good hunting ground for clusters and associations. Around 100 galactic clusters and 200 associations have been found there — some as far as 80,000 light-years from the nucleus. The dense inner regions of the associations are about the same size as those in the Milky Way. The richest one is NGC-206, which bears a strong resemblance to the double cluster in Perseus. M-33, the late type spiral galaxy in Triangulum, also has about 300 known galactic clusters. Beyond the Local Group of galaxies, no galactic clusters have been picked out; at such great distances they are too small and too faint.

it sounds, for stars orbit the galactic center at some 300 kilometers per second. But it does mean that an association has a fleeting lifetime; the ones we see must be fairly young objects. In the nearby association surrounding the blue supergiant Zeta Persei, for instance, more than a dozen members stars are bright enough that their positions have been accurately measured for more than a century. The measurements show that they are moving outward from the center of the group. Tracing back along their paths, we find that they were all near the center a mere 1.5 million years ago! This time is called the *expansion age* of the association. The oldest existing associations can be no more than a few tens of millions of years old — very short in a galaxy's lifetime!

The most familiar association in the solar neighborhood is the *Orion association*. It consists of four distinct parts, each having a slightly different age. In the constellation Orion the hunter, these subgroups form the right shoulder, belt, sword, and the region just around the Trapezium cluster. The oldest subgroup is around 4.5 million years old, while the youngest may have existed for less than 100,000 years. Two stars that are now far apart in the sky — Mu Columbae and AE Aurigae — appear to be moving *in opposite directions* away from the Orion association at very high speeds (over 100 kilometers per second). If they are traced back to their probable origin in the association, they appear to have left it a little more than two million years ago. The escape of these "runaway stars" is another unsolved puzzle. Are they the leftovers of binary systems in which the companion, a much more massive star, supernovaed, hurling the smaller star into space like a stone from a slingshot?

Around the Orion nebula is a hotbed of star formation. The visible nebula may be only the front edge of a vast cloud of gases, weighing over 100,000 solar masses. Ammonia, water, formaldehyde and hydrogen cyanide — all of which may be important for the formation of life — appear in this cloud, as well as methyl alcohol, formic acid and ethyl alcohol. At the front of the molecular cloud, where we see the visible Orion nebula, are two bright infrared sources (one, an extended nebula, and the other a starlike object). A cluster of protostars with a total of over 1,000 solar masses is apparently being born in this area.

A very young cluster, in which the smaller, redder stars have not even settled down to the main sequence, is often found at the heart of a young association. *Trapezium* systems like the one in Orion are also common; these are multiple stars in which the separations of the components are about the same. Such systems are much less stable than multiple stars in which the separations differ greatly (such as the famous double-double multiple star Epsilon Lyrae), so Trapezium stars must be very young objects.

Besides the OB associations there are also *T associations*. These are groups of T Tauri stars — irregular variable stars with spectral types rather like our sun, but having an anomalous hydrogen-line emission. T associations are found only in regions with bright or dark interstellar clouds and plenty of obscuring dust. The T Tauri stars themselves have just formed from the surrounding dust and gaseous material, and are still in the process of contracting. They are so young, in fact, that they have not reached the main sequence. Other types of variable stars also occur in T associations, as well as nonvariable stars and Herbig-Haro objects (small nebulosities containing starlike condensations, which are thought to be star groups at the very beginning of life). Although only about three dozen T associations are known, they contain nearly 12,000 dwarf variable stars, and appear to be the main source of low luminosity stars in the solar neighborhood.

Where do stellar associations fit into the galaxy? Interestingly, they turn out to be almost the definition of what a spiral arm *is*. They are the best way to trace the spiral structure of our galaxy. Because they are so young, OB associations have not had time to stray from the spiral arm where they were formed. In the solar neighborhood (where the spiral pattern is hard to pick out simply because we are immersed in it), the pattern of OB associations shows that there is an inner spiral arm in the direction of Sagittarius, and an outer arm in Perseus. Between them is the Orion arm, which splits and does not run quite parallel to the other two. Our sun seems to lie on the inner edge of the Orion arm (see "Exploring the Milky Way, Part 1", ASTRONOMY, August 1976).

Young galactic clusters also outline the spiral arms fairly well, but older clusters show no connection at all with spiral structure — they've been scrambled too well by making several trips around the galactic center. The overall significance of these observations is astounding: Spiral arms *are* the birthplaces of stars; we see them because they are full of young, blue, luminous stars in bright clusters and associations!

The sun itself may have formed in an association now long dispersed. Although we now travel a solitary path about the galactic center, some five billion years ago the sky of primitive Earth may have sparkled with bright members of the sun's long lost contemporaries. But the story of star formation continues today — in the T associations, the starbirth regions of Orion, and raw new clusters that have come into being since the ancestors of man first walked on Earth.

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RIVAL COSMOLOGIES

by
Barry Parker

Time: 20 billion B.C. The primordial nucleus had just developed an instability. Suddenly there was chaos as an explosion of indescribable intensity took place. Particles and radiation spread outward at an unbelievable rate. The first few seconds were beyond imagination. Gradually, over the billions of years that followed, a semblance of order began to emerge. Tiny points of light (stars) appeared as the knots of gas and dust contracted, and on a larger scale, galaxies formed. But the overall expansion continued. Even today as we look out into the universe, we see that is still expanding.

What is the best picture of our universe? Presently, the *big bang* theory — which invokes the primordial explosion — is most widely accepted. But the big bang has had — and still has today — a variety of important rivals.

In 1948, Thomas Gold and Herman Bondi, both of Cornell University, began looking at the possibility that there may never have been a gigantic explosion. According to them, the universe may have always been expanding. Indeed, we may live in a constant, unchanging, ever expanding steady state universe. Their work is built upon Albert Einstein's earlier *Cosmological Principle.* According to it, on a sufficiently large scale, the universe is the same everywhere, regardless of where you happen to be in it. But Einstein said nothing about *time.* Bondi and Gold extended Einstein's ideas to all time in their *Perfect Cosmological Principle.* They postulated that the universe is the same to every observer regardless of position and time. In other words, the universe has always expanded and always will be expanding, as seen from any place in it, and every observer will always see stars and galaxies much as we currently see them!

But if the universe were to stay exactly the same, its average density would be constant. Therefore, because expansion means the density drops, matter must be created somewhere. Bondi and Gold assumed this matter just appeared "out of nowhere". Since only a small amount was needed — about one hydrogen atom every 100 million years or so just appearing in the volume occupied by a house would do nicely — no adjustments were needed in the rest of physics!

Unknown to Bondi and Gold, a third person — Fred Hoyle of Cambridge University — was also working on similar ideas. Hoyle supplied the theory with a mathematical basis and eventually became its most ardent supporter. All three men are now jointly credited with the theory, which is called the *steady state cosmology.*

How could matter just pop into the universe? Bondi, Gold and Hoyle assumed, in fact, that the amount of new matter appearing was just sufficient to offset that lost by expansion. But how does the universe know how much extra matter is needed? Many scientists saw this as a serious flaw. In addition, there was the "forever" aspect of the steady state: It said that the universe was always here, that it had no beginning and will have no end, and that it's an infinite universe — one that goes on forever and ever. Although infinities are difficult to visualize and scientists don't like them, the steady state was widely accepted for many years.

As Hoyle pointed out, there may be problems with the infinities and matter creation of the steady state, but the big bang theory doesn't answer these questions either. It simply avoids them. Where did the matter that exploded outward (the primordial nucleus) in the big bang come from? Well . . . it was just there, the big bang cosmologists might answer. How long was it there? There are plenty of problems with the big bang theory too!

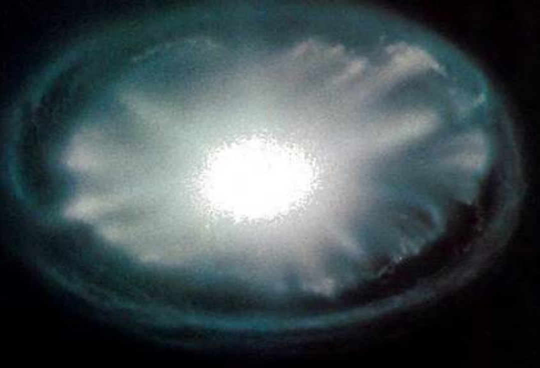
However, as far as most cosmologists are concerned, the steady state theory has more problems. A major setback occurred in 1965, when physicist Robert Dicke of Princeton examined the mathematical details of the big bang. He realized that a primordial explosion should have given off radiation early in its expansion and, in fact, the radiation should still be around. He predicted that it would be in the microwave region of the spectrum — weak but present! Unknown to Dicke, physicists George Gamow, Ralph Alphner and Robert Herman had predicted the same phenomena many years before, but suitable radio techniques weren't available, so it had been forgotten.

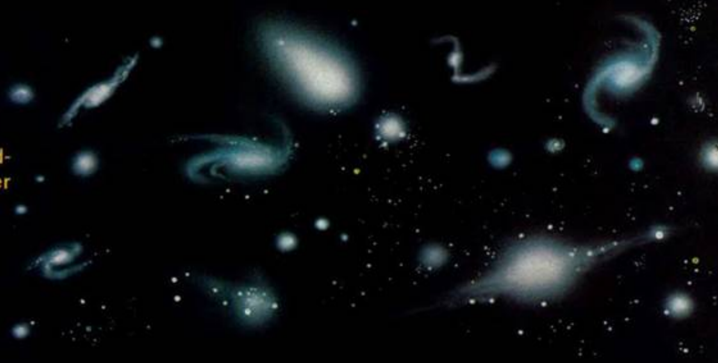
Dicke decided to build a radio telescope to detect this radiation. Before he finished it, however, news reached him that two Bell Laboratories scientists, Arno Penzias and Robert Wilson, had picked up a faint background hum in a radio telescope they had just built in Holmdel, N.J.

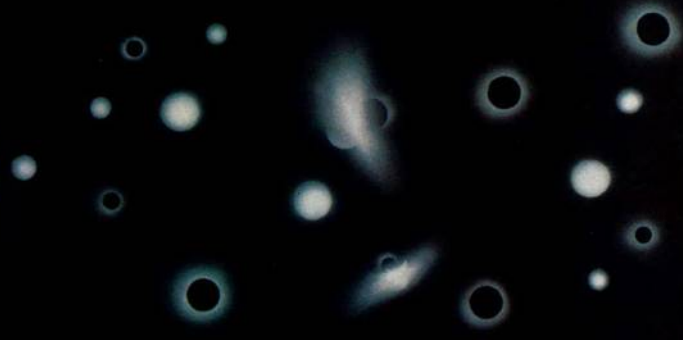
Sure enough, the radiation was exactly what

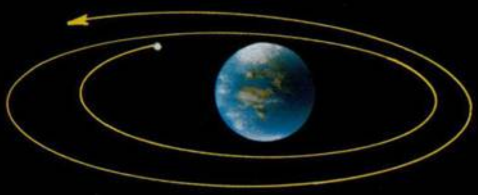
The Rival Cosmologies

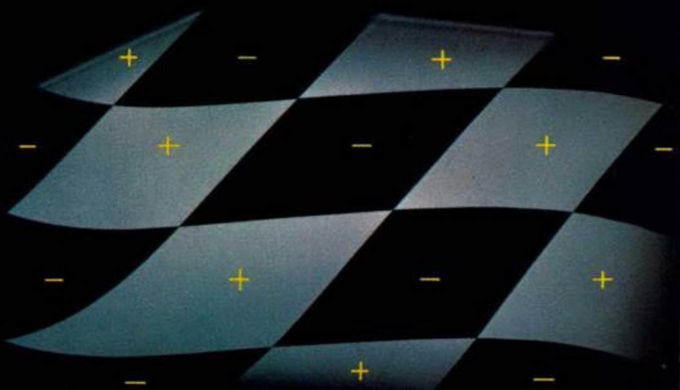
COSMOLOGY	DESCRIPTION
BIG BANG	At some time in the past the universe began with a great explosion of incredible intensity. The universe continues expanding today.
STEADY STATE	The universe always existed and always was expanding. In order to keep up this expansion, matter appears out of nowhere.
ANTIMATTER	Theoretically, a metagalaxy composed of particles and antiparticles can exist until gravity pulls them in. Then they collide and disappear in a burst of energy equal to the sum of their masses.
VARYING G	A constant, such as gravity, changes with time. As gravity decreases, processes throughout the universe undergo a gradual change.
PARTICLE CHANGE IN SPACE AND TIME	An object's mass depends on its position in space and time. In far distant space are objects billions of years old. These objects appear to have less mass than they *actually* have. Farther on are objects with no mass. Farther yet is the universe's edge and the beginning of a universe of the opposite sign.

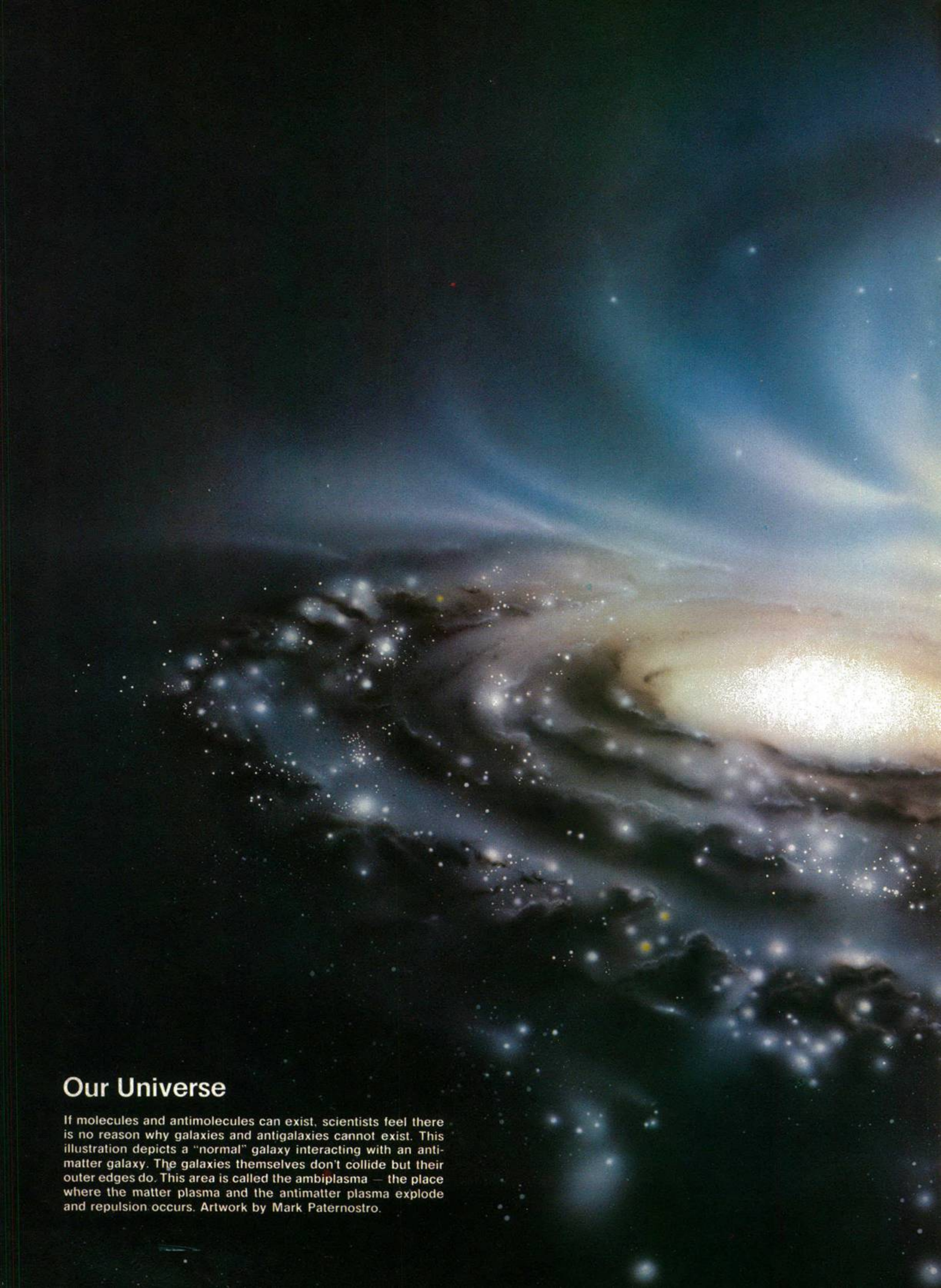












Our Universe

If molecules and antimolecules can exist, scientists feel there is no reason why galaxies and antigalaxies cannot exist. This illustration depicts a "normal" galaxy interacting with an antimatter galaxy. The galaxies themselves don't collide but their outer edges do. This area is called the ambiplasma — the place where the matter plasma and the antimatter plasma explode and repulsion occurs. Artwork by Mark Paternostro.

he and Gamow had predicted. It was in the microwave region of the spectrum and had an effective temperature of three degrees Kelvin. The steady state was obviously in trouble, since it didn't predict such radiation. Hoyle, along with cosmologist Jayant Narlikar, worked to bring it into accord with the new discovery. But as modification after modification was added, the theory began to look patchy.

If a vote were taken among astronomers today, the big bang theory would no doubt be overwhelmingly favored. But cosmological questions are not settled by popularity votes: The evidence is still not all in!

The steady state theory is now relegated to the role of a "rival cosmology". It may be the most important rival of the big bang theory, but it certainly isn't the only one. Prominent are the *antimatter cosmologies* which assume that the universe contains antimatter, in addition to ordinary matter. What is antimatter? We'll leave the details until later, but for now will mention that if a piece of matter and a piece of antimatter collided, they would both disappear in a tremendous explosion. On the basis of this, it should be obvious that antimatter is quite different from matter.

Another type of rival cosmology assumes that the fundamental constants of nature (such as the strength of gravity or electric forces) vary slowly over millions of years. The most important of these rely on changing gravity, so they are referred to as *varying G cosmologies*. Still other, more exotic cosmologies assume that the universe isn't expanding at all! How could this be? Everyone knows the spectral lines of distant galaxies are shifted toward the red, and that this means they are moving away. It is possible, however, that the redshift is caused by something else. As a group, such cosmologies are called *tired light cosmologies*. And finally, we have cosmologies that assume that the masses of fundamental particles change in space and time.

Now, let's go back to the real universe. Is it possible that any of these unusual theories could be a good representation of it? Let's consider each in detail and compare it to the facts.

Antimatter Cosmologies

Antimatter was postulated by physicist Paul Dirac in 1930. According to his calculations, there was a particle corresponding to the electron which was the same as an electron in all respects except charge — instead of a negative charge, it had a positive charge. A few years later the anti-electron, or positron as it is now called, was discovered. And, as we mentioned earlier, when an electron and a positron were brought together they both disintegrated in a burst of energy. Within a few years, the antiproton was discovered, and then the antineutron. Over the years the list of antiparticles has continued to grow, until now it includes the counterparts of all known particles.

Scientists began to wonder about the possibility of atoms and molecules of antimatter. But if "antiatoms" and "antimolecules" can exist, why not entire systems — stars and galaxies — of antimatter? There is no reason why they can't exist, as long as there isn't too much matter around. Antimatter galaxies wouldn't *look* any different from galaxies composed of matter. It's quite possible that many of the galaxies we see are antimatter galaxies.

There are reasons for believing that there is a considerable amount of antimatter in the universe. If matter is created to replace that lost by expansion, there is a good chance that it is being created in the form of particle/antiparticle pairs. Pairs of this type (such as electron/positron pairs) are easily created in the laboratory. Moreover, it is the only way to convert energy into matter, so it's natural to ask if it's also important in the production of matter out in space. If it is, in fact, the way the universe replenishes itself, we might expect the universe to be composed of half matter and half antimatter. Nature likes symmetry — and such a universe would be symmetrical.

But the observational evidence does not point to a symmetrical universe. It does not even indicate there is much — if any — antimatter. The cosmic rays, for example, that continually bombard Earth, are composed of several different types of particles (see "Gamma Rays and the Origin of Cosmic Radiation", ASTRONOMY, June 1977) likely come from the distant reaches of our galaxy and possibly beyond. Careful analysis has shown, however, that the particles of cosmic rays are entirely (within present experimental limits) matter. Antimatter is not detected. Other tests have also been made for evidence of antimatter. Clusters of galaxies have been searched for evidence of gamma rays, which would suggest the presence of antimatter. None has been found, so the verdict seems clear: There just isn't any antimatter, unless it's extremely well hidden.

Not only is there little direct or indirect evidence for antimatter, but if it were here we would have to make some radical changes in our theories. If the material that was ejected in the big bang explosion were, for example, half matter and half antimatter, cosmologists would have problems explaining where all the matter we now see in the universe came from. One of the major difficulties of symmetric cosmologies is the *annihilation catastrophe*, in which the particles (or even whole stars) could collide and disappear, giving off energy. According to recent calculations, if the universe was originally symmetric, it now has nine times too much matter left in it! The only way the annihilation catastrophe could have been avoided is if the matter and antimatter were somehow separated at early times (that is, within 1/10,000 second after creation).

How could this have occurred if they were both in the primordial nucleus? R. Omnes of the University of Paris has suggested that the initial temperature was so high that they were sufficiently separated. But there are problems with this approach too!

Hannes Alfvèn and Oskar Klein have taken a different approach. They introduced the concept of a *metagalaxy*, in which creation begins with an immense sphere about a trillion light-years across containing a uniform distribution of matter and antimatter. Gravity acts to slowly pull the particles toward the center of the sphere. As the sphere gradually contracts, the infalling material gains momentum until eventually particles and antiparticles begin to collide and annihilation occurs. Radiation pours out into the universe; finally, a tremendous outward radiation pressure builds up. The inward compression becomes an explosive expansion as its momentum is stopped and reversed.

The Klein-Alfvèn theory also has problems — most of them centering around the finite size of the metagalaxy. To properly account for the microwave background radiations, the sun must be placed in the center of the metagalaxy, meaning that our sun is at the center of the universe. If this is true, the annihilation temperature may be too low to produce the background radiation.

The theory poses an interesting question: Does matter attract antimatter? Matter attracts matter via gravitation, but we're not sure about matter and antimatter. If it doesn't, some of our basic theories (such as general relativity) are in trouble.

Varying G Cosmology

A second rival is the varying G cosmology. There are several variations, and again we have Dirac to thank for introducing them. Since they are centered around the fundamental constants of nature, let's begin by briefly discussing these constants.

The most important of them, as far as cosmology goes, is G, the universal gravitational constant. Others are the mass and charge of the electron. The speed of light is also a constant of nature, as is Planck's constant which is important in atomic physics. Dirac lumped a few other things in with these constants — things such as the radius and average density of the universe (which are not really fundamental constants). He looked at the ratios that could be formed from these numbers — particularly ratios where the units cancelled. We call these *dimensionless ratios*, because there are no units attached.

Dirac compared such things as the electric force and the gravitational force between a proton and an electron, the radius of the universe and the radius of the electron. In doing so, the number 10^{40} occurred so often that he felt it must mean something.

But the radius and age of the universe change. If these ratios (now commonly called *cosmic ratios*) were to remain constant at 10^{40}, it meant that something else had to change too. In other words, one of the other constants was not really a constant, but had to change slowly to compensate for the changes in the universe. Dirac assumed this was G, the gravitational constant, and on this basis formulated a cosmology.

Dirac's cosmology was soon found to have problems: It did not agree with observations and had to be discarded. But varying G cosmologies did not die with it. In 1947, P. Jordan, a physicist, resurrected them with the introduction of one that overcame many of the problems Dirac had encountered. He allowed particle creation in his theory; in addition, he also introduced a special mathematical notation to account for the gradual decrease of G. But Jordan's theory also fell short of expectations. Other similar theories have been developed by cosmologists Dicke and C. Brans, and by Hoyle and Narlikar.

As soon as we seriously consider any of these theories, we naturally look for observational evidence that G is gradually decreasing. In all theories, the decrease is exceedingly small — too small to be noticed in routine observations. A special test of some type would have to be made. Let's look at what would happen if G did decrease.

First, if G was greater in the past than now, stars would have been much hotter then. And since our sun is a star, it would have been hotter in the past than is now assumed. Earth, too, would have been hotter. If there is strong evidence for this, scientists haven't yet found it.

If G is less now than it once was, Earth must once have been smaller. As G decreased, it would have gradually expanded. Is there any evidence for this? Some evidence lies along ocean floors as large rifts or cracks. An expanding Earth cracking could have made these rifts, but geologists now think they understand the rifts without needing to make changes in G.

Another effect of a decreasing G would be a change in the orbit of the moon. The moon would gradually move outward as gravity became weaker. Of course, there are a lot of other things (such as tides) that cause similar changes, and they would have to be considered. Thomas C. Van Flandern of the U.S. Naval Observatory has looked at recent changes in the orbit of the moon and believes he has evidence for a small but definite change in G. He used lunar occultation data to substantiate his claims. The moon occults many stars as it travels around Earth. If the time of occultation were known to sufficient accuracy over a long period, we would be able to detect a change in G. It turns out that in the mid-1950s, astronomers began using atomic clocks to time occultations. Van Flandern has checked the difference in occultation times over the past 20 years. Many corrections had to be made (for solar wind, comets, meteors, etc.). With all of them taken into account, he still had a small residual and is convinced this is caused by a small change in G.

If he does have a small residual, it may be associated with G — but then again, it may be associated with something else. He has, for instance, based his assumption on atomic clocks which also depend on constants of nature (the charge of the electron, Planck's constant, etc.). If any of these constants changed during the last 20 years, the measurements would also have to be changed.

Particle Change in Space and Time

Several cosmologies based on changes in the mass of subatomic particles have also been formulated. The most mind boggling of these is based on a principle formulated many years ago by physicist Ernest Mach and modified by Hoyle. According to Mach, local phenomena depend not only on local objects but on every bit of matter in the universe. Using this as a basis, Hoyle set up a cosmology.

According to Hoyle, the mass of an object depends on its position in space and time. Earlier in time, all objects had less mass. As astronomers probe outward into space, they see objects as they were millions and even billions, of years ago. We therefore are observing objects with much less mass than they have today. Indeed, if we look far enough, we see objects with almost no mass. Just beyond this is the edge of our universe, according to Hoyle.

But what is on the other side of this edge? Hoyle looked further (mathematically) and found that on the other side there was mass of opposite sign — just as negative charge is opposite to positive charge. In fact, there was an infinite number of aggregates or universes, each of opposite charge, bordering one on the other.

The universe on the other side of the boundary nearest us is completely cut off since, according to Hoyle, you cannot communicate across a boundary. But this boundary serves a useful purpose as far as Hoyle was concerned. Remember, there is no initial explosion. Hoyle's is a steady state theory. But we know, of course, that the cosmic microwave radiation is present. We've observed it — and it's usually attributed to the primordial fireball. Hoyle's theory supposes that the microwave background is starlight from bordering universes that has merged through the boundary. As it passes through, it changes in character so on our side it becomes microwave radiation.

As mind boggling and crazy as Hoyle's theory sounds, it is consistent with present observation and Einstein's general theory of relativity; it is a kind of generalization of the theory — one with a varying mass. According to Hoyle, Einstein's theory is completely satisfied only near a boundary, which means we must live near a boundary.

Whether this theory can ever be proven remains to be seen. It is now, however, the only varying mass cosmology. Dirac has generalized his earlier work to include varying mass. And physicist Shimon Malin of Colgate University has introduced a cosmology based on a modification of general relativity that includes varying mass. Malin and Victor Mansfield (also a Colgate physicist) have, in fact, made a study of the evolution of giant elliptical galaxies in an effort to see which of the varying G cosmologies is most consistent with nature. They report contradictions for Hoyle's and one of Dirac's theories, and feel that their results most strongly support Malin's theory.

Nonexpanding Universe

So far we've discussed only theories in which the universe is expanding. But there are several theories where the redshift of distant galaxies is assumed to be caused by things other than expansion. Most important of these are the tired light theories. The original tired light theory was formulated in 1935 by cosmologists Richard Tolman and Edwin Hubble. They assumed some unknown phenomenon gradually decreased the energy of light as it passed through space. As energy was lost, the waves lengthened, shifting spectral lines toward the red.

But what is there in space that would cause a gradual loss of energy? If the light was scattered by space dust, there would be a loss, but space just doesn't seem to be that dusty. A light beam would encounter more dust traveling a few miles through our atmosphere here on Earth than it would over billions of miles in space!

We could assume some kind of direct interaction between the photons of light and space itself. If we did, however, we'd only be guessing, since there is presently no known interaction of this type.

Another problem for tired light theories has been pointed out by Russian scientist Ya B. Zel'dovich. Distant images would become smeared if there was a loss of energy: The stars would not be points, but would be small disks. We know, of course, that this is not the case. And unless someone finds a clever way around these problems, tired light theories seem to be doomed.

We have looked at many of the rival cosmologies — the steady state theory, varying G theories, antimatter theories, varying mass theories, tired light theories — and found that, while interesting, none remain as serious competition to the big bang theory. But science is a search; a sudden discovery may bring one of these theories back to the limelight. There might be a gradual transition as many small discoveries are made undermining the big bang — or an ongoing confirmation as increasingly delicate observations fall in line with big bang theory predictions. Things will no doubt change in the next 20 or so years. What these changes will be, we can only guess.

Barry Parker is an associate professor of physics and astronomy at Idaho State University where he has taught courses in descriptive astronomy, astrophysics, cosmology and astrophotography. His main interests are black holes and cosmology; he is presently writing a popular level book on the latter.

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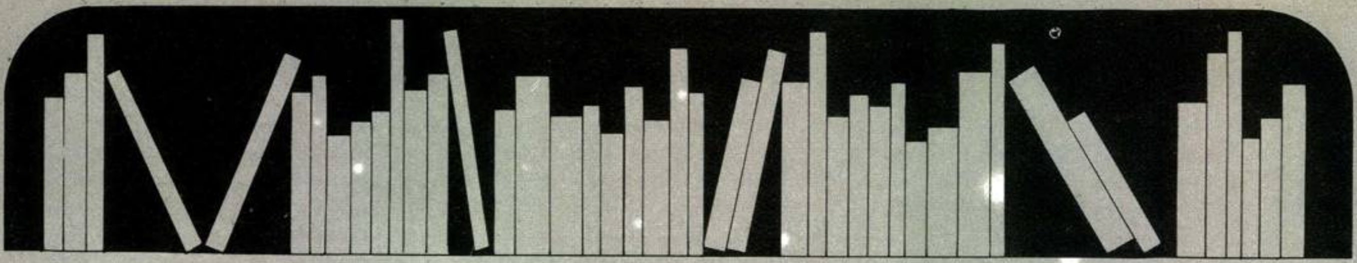

ASTRONOMY REVIEWS

Planetary Geology
by NICHOLAS SHORT

362 pages, hardcover, $17.95
Prentice-Hall (1975)

Geology was named after Gaia, the Greek goddess of Earth, while other planets were only "wanderers" in the sky. Now the other worlds in space are becoming targets for mineralogists as well as astronomers. Perhaps astrogeology is a more appropriate term, but the origin of this artificial word is somewhat confusing. Planetology is too broad a term, since it covers worlds like Jupiter which may only be of interest to meteorologists, chemists and biologists, but not to rock geologists. For them, the area of study is planetary geology.

This book is designed to be a college level semester course for geology majors, not astronomers. Mainly concerned with a geologic comparison of Earth and the moon, it also tackles data obtained from Mars, and contains a hurried insert (with little analysis) about Mercury and a few speculations about Venus. The concentration on Earth and the moon, nevertheless, is still very useful, although the book seems very disorganized.

An introductory chapter on the history of space exploration appears to be filler material, and students might better survey the events leading up to interplanetary exploration in some other book devoted to that topic specifically. The brief chronology of the Apollo program contains a few errors.

After an introductory section on the structure of the solar system (which should serve as a review for astronomy students), Short discusses the oldest branch of extraterrestrial geology — the often ignored science of meteoritics. The survey of the physical appearances of meteorites, their chemistry, sources and meaning to the "big picture" is very well done and is a good introduction to the "meat" of the book.

Short then backtracks a few billion years to discuss the origins of the planets, and follows with another historical chapter on what was known or assumed about the moon before the era of space exploration. The chapter could have been written 20 years ago, and may well have been. Perhaps in a sequence of lectures this presentation might be more coherent, but the reader soon becomes annoyed at the disjointed themes being thrown at him. Each individual theme is well treated, but jointly they have little relation to each other. This disorganized approach is probably the book's greatest drawback.

The structure of the book continues to be puzzling with a chapter entitled "Previews of the Lunar Surface". This text is not supposed to be a historical summary of how mankind explored the moon; it was to have been a compilation of everything we have learned about the moon by any method and at any time.

The chapter sequence remains unsatisfactory when the moon is put aside for a detour into cratering. Again, this is an excellent stand-alone section; it is only with relation to the rest of the book that it is strange. Craters on Earth, the moon and Mars are compared and explained, and an extensive subsection on experimental cratering work (nuclear, high volocity bullet impact, and computer modeling) is appropriately included.

Next, lunar igneous processes are described, followed by a section on how to map the moon, before men finally reach the satellite. Each mission is presented exhaustively from a geologist's point of view, along with descriptions of the lunar surface and orbit scientific instruments and findings. The mineralogy of the lunar samples is described, and a final chapter covers the other terrestrial planets.

The best pages are at the end; they are the promised reason for the rest of the book, but in a typical college course might regretably be dropped or rushed at the end of a semester spent examining the details of the earlier sections. Here the different discoveries are analyzed, compared and correlated in an attempt to find out what it all adds up to. Geologists are in the middle of this question, and have already come up with some good answers.

This large and profusely illustrated textbook can indeed form the basis for a college level course. It is written clearly enough (though disjointedly) for the individual reader, and is as up to date as a hardcover text can be in such a fluid field. Strange as it once may have seemed, astronomers should indeed study rocks! *James E. Oberg.*

◆

1977 Yearbook of Astronomy
edited by PATRICK MOORE

204 pages, hardcover, $9.95
W.W. Norton & Company, Inc. (1976)

The only notable change in this, the 16th **Yearbook of Astronomy**, is the addition of monthly notes and charts for those observing from the southern hemisphere. Otherwise, it closely follows the style and format of previous installments. Ably edited by Patrick Moore, the well-known British popularizer of astronomy, it is simply jam-packed with bite sized chunks of fascinating reading in addition to its observing data and charts.

This volume is divided into three basic parts. The first gives the sky events for each month of 1977 which were easily visible to the unaided eye — mainly the aspects of the moon and bright planets. Those purchasing the **Yearbook** now will obviously find this feature of limited value, but the many informative notes on sky objects still make this section worth reading. The accompanying constellation charts have black stars and connecting lines on a white background and serve their purpose well. They are, however, drawn for the latitude of the British Isles (52 degrees).

The second part of the book is the articles section, contributed by active workers in the field like David Allen, Peter van de Kamp and Moore. Topics covered in this edition concern John Flamsteed, the surface of Venus, Jupiter's satellite Io, unseen companions of nearby stars, ice and dust clouds in space, the Viking mission to Mars and recent advances in astronomy. It is this continuing series of mini-articles throughout the 16 volumes of the **Yearbook** that constitute its lasting value to readers.

The final portion contains brief lists of interesting deep sky objects for small telescopes. Though by no means complete rosters of the sky's finest showpieces, they do provide an adequate introduction to this ever popular field of observing. This section concludes with notes on some recent books on astronomy, and on the individual contributors for 1977.

Altogether, the **Yearbook of Astronomy** is well worth reading and buying (especially if you already have its predecessors). It should make good company on these long cloudy cold nights! *James Mullaney.*

◆

The High Frontier: Human Colonies in Space

by GERARD K. O'NEILL

288 pages (illus.), hardcover, $8.95
William Morrow & Co. (1977)

Futurist and science fiction writer Arthur C. Clarke once said that all new ideas go through three stages. First they are impossible. Then they are barely possible but hideously expensive. Then they are obviously a good idea, and were so from the beginning! Human colonies in space seem to have progressed remarkably rapidly to a point between stages two and three.

The idea of having industrial processes in space so extensive that tens of thousands of people will be needed in orbit is an awe-inspiring one, especially since it has been in the news media for less than three years. But already it has spawned a series of books, a society complete with "L5" newsletter, and now this definitive work by the man who started it all — Princeton physics professor Gerard O'Neill.

O'Neill, who had been barely too old to be an astronaut in 1967, asked his students whether or not the surface of a planet was the optimal location for an industrial civilization. After months of study, the answer was "no". Artificial worlds in deep space, with gravity provided via centrifugal force when needed, turned out to be a plausible alternative.

In this readable and constantly surprising book, O'Neill paints an image of just such a civilization, which may be only decades in the future. The style varies from chapter to chapter — first that of a college professor, then that of a philosopher, and then that of a fictional space colonist of the next century writing a letter back to Earth. It is an effective mix.

The book is written from an advocate point of view, but is successful in its attempt to portray all factors which may support or attack the ideas. It is an excellent introduction to the idea of colonies in space, and will go far toward dispelling the major roadblock to this endeavor. Most people may find that their initial impressions of the whole idea are incredulous and negative. But with a little reflection and some hard information, most of these initial doubters soon realize that it might happen. It might be desirable — even urgent — to make it happen. At the very least, it is possible, although very expensive; at best, it was a good idea from the beginning. *James E. Oberg.*

◆

Objectives and Models of the Planetary Quarantine Program

by MORTON WERBER

140 pages, paperback, $2.10*
U.S. Government Printing Office

Before Viking reached Mars, one of the surface experimenters remarked that he didn't think that bringing Mars soil back to Earth would be dangerous. "As a matter of fact, I would be willing to eat it", he said, as proof of his confidence. But following the amazing activity of the first few weeks in the soil sample ovens, the scientist retracted his statement at a press conference. It was all in fun, but it did underline the problem of planetary materials contaminating other planets.

During the first 20 years of space exploration, there has been "great scientific concern that the search for life might be compromised by terrestrial microbial contamination during early space exploration projects before effective life detector systems can be added to the space program." With the return of Martian samples, and the extension of the search for life to many seemingly inhospitable worlds, this topic is becoming increasingly more timely.

This NASA booklet expresses the history of that concern, as experienced by scientists and scientific organizations. It carefully chronicles the fumbling guesswork and statistical games which early specialists in this field were forced to work with. Everything was conjecture and estimation; the mathematics, while impressive, were based on supposition.

This whole booklet is based on little else. Nitpicking arguments over the true meaning of the word quarantine (based on the French word for "forty", the time in days a diseased ship had to remain isolated in a harbor) are excruciatingly boring to the average reader. Minutes of United Nations space subcommittee meetings may be of vague interest to the international archivist, but not to those interested in "planetary quarantine" instead of "planetary quarantine programs". The booklet's title is precisely descriptive of its contents, and this is a disappointment.

Much interesting material remains to be documented for the general public. The contribution of overzealous sterilization techniques to the failures of the early Ranger moon program (1962-65) has never been satisfactorily disclosed, and this book also ignores such practical topics. While reporting on several laboratory attempts to replicate the effects of extraterrestrial conditions on stowaway microbes, the book .completely overlooks the actual two-year survival of terrestrial life forms on the moon inside the Surveyor 3 camera (retrieved by Apollo 12).

Despite international space quarantine conferences, the USSR has given no details on their own programs and techniques. Bland public, reassuring announcements are regularly released, while private meetings with Western colleagues reveal that the actual standards for Soviet probes which have landed on Venus and Mars are highly questionable. Nobody who knows for sure is willing to talk about it in enough detail.

This has not kept COSPAR (the Committee on Space Research, an international group associated with the UN's Committee on the Peaceful Uses of Outer Space) from issuing interplanetary quarantine decrees. Some of these decrees cost the United States space program millions of dollars to meet standards which some feel are far too high, and which Russia has given no proof that it is abiding by. For example, COSPAR has forbidden the impact on Mars of any unsterilized spacecraft before Dec. 30, 1988 (soon to be extended to 2018, after careful deliberation). This essentially makes a manned Mars landing illegal, unless more years of debate amend this international law.

Aficionados of Carl Sagan's exobiology equations will find some here, together with pages of symbol definitions. But these obsolete estimates are virtually irrelevant today. The moon has essentially been removed from quarantine by the Apollo program, while Mars has become a true biochemical target with all the resulting problems of "back contamination". Interplanetary quarantine is a far more urgent problem than this scholarly review of documents indicates. A better report is needed. *James E. Oberg.*

**Published by NASA (1975); college level. Stock number SP-344; available from Superintendent of Documents, Washington, D.C. 20402.*

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The Astroscan 2001 — a major breakthrough in Edmund Scientific Company's 35-year commitment to astronomy.

Now, An Affordable Rich Field Telescope Rivaling Any Instrument You May Have Used.

The Edmund Astroscan 2001 is a unique instrument created to provide compact and convenient portability without sacrificing the quality optics required for effective and satisfying astronomical viewing. And, at just $149.95, it represents the telescope bargain of the decade!

The 2001 is a classic Newtonian reflector telescope system enclosed in a high-impact plastic body which is both practical and eye-catching. Its optical system provides the clearest, brightest, most spectacular wide-angle views of the heavens you've ever seen. *The fully coated optics in the* Astroscan 2001 are comparable to those used in professional telescopes. Extreme simplicity of design, the result of months of sophisticated engineering and testing, enables you to take this fine instrument anywhere and use it almost instantly.

Wide Field View Shows You More

The Edmund Astroscan 2001, a true "wide field" telescope, provides a giant 3° field of view with a resolution you'll find hard to believe in an instrument this inexpensive. You'll see more stars in a single view with greater clarity, with greater ease than you've ever thought possible.

Take It Anywhere — Use It Anywhere!

The 2001 weighs just over 10 pounds and is only 17 inches long. It can set up in seconds. Anyone, even a young child, can use it easily.

Its 4¼" diameter parabolic primary mirror is precision polished to a tolerance of ⅛ wave. A ⅛ wave diagonal mirror supported from an optical quality coated window and a 28 mm focal length compound, achromatic eyepiece complete the optical system. Everything is pre-collimated requiring no user adjustments and *the system is protected from dust* and moisture by the window. The 2001 gives you a 17½ inch objective focal length with an effective magnification power of 16X. *There is no other telescope like it!*

Easy to Use

A uniquely designed, cast aluminum mount enables you to aim and use the 2001 with a simple fingertip control. Plus a selection of available accessories make the Astroscan 2001 the most versatile instrument *you've ever used.* Its phenomenal light-gathering power lets you see stars as faint as the 12th magnitude under good viewing conditions opening new astronomical vistas you've only hoped for until now.

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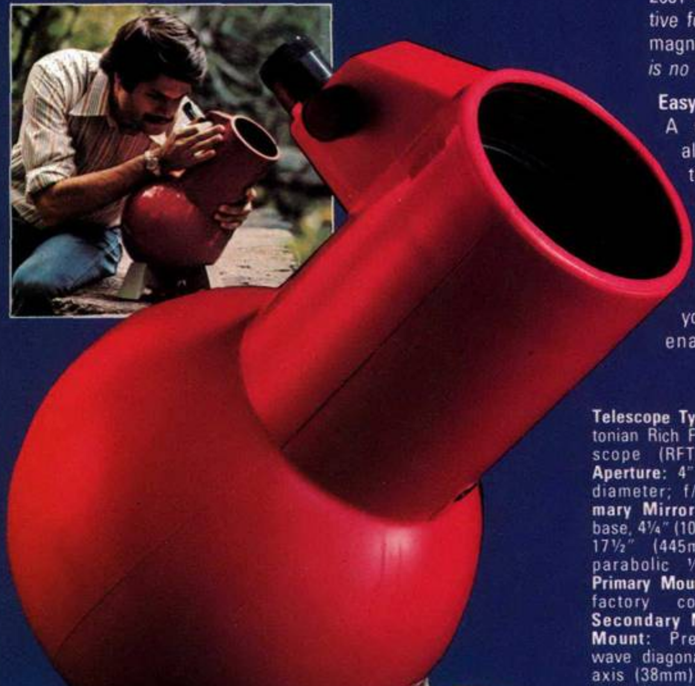
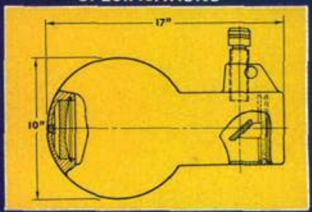


SPECIFICATIONS

Telescope Type: Newtonian Rich Field Telescope (RFT). **Clear Aperture:** 4" (102mm) diameter; f/4.4. **Primary Mirror:** Pyrex® base, 4¼" (108mm) dia. 17½" (445mm) F.L. parabolic ⅛ wave. **Primary Mount:** Fixed, factory collimated. **Secondary Mirror & Mount:** Pre-aligned ⅛ wave diagonal 1½" minor axis (38mm) mounted to coated optical window.



Eyepiece: 1¼" O.D., 28mm F.L. compound Achromatic. **Power:** 16X with above eyepiece. Other eyepieces or optional Barlow lens may be used to increase power. **Field of View:** 3.0° with eyepiece supplied. **Focusing:** Smooth, posi-grip, rubber roller focusing (25 feet to infinity). **Telescope Body:** Special, high-impact plastic. **Dimensions:** Length: 17" (432mm); Sphere dia.: 10" (254mm). **Weight:** 8.4 lbs. (3.8kg) without stand. Stand weight 2 lbs. (0.9kg).

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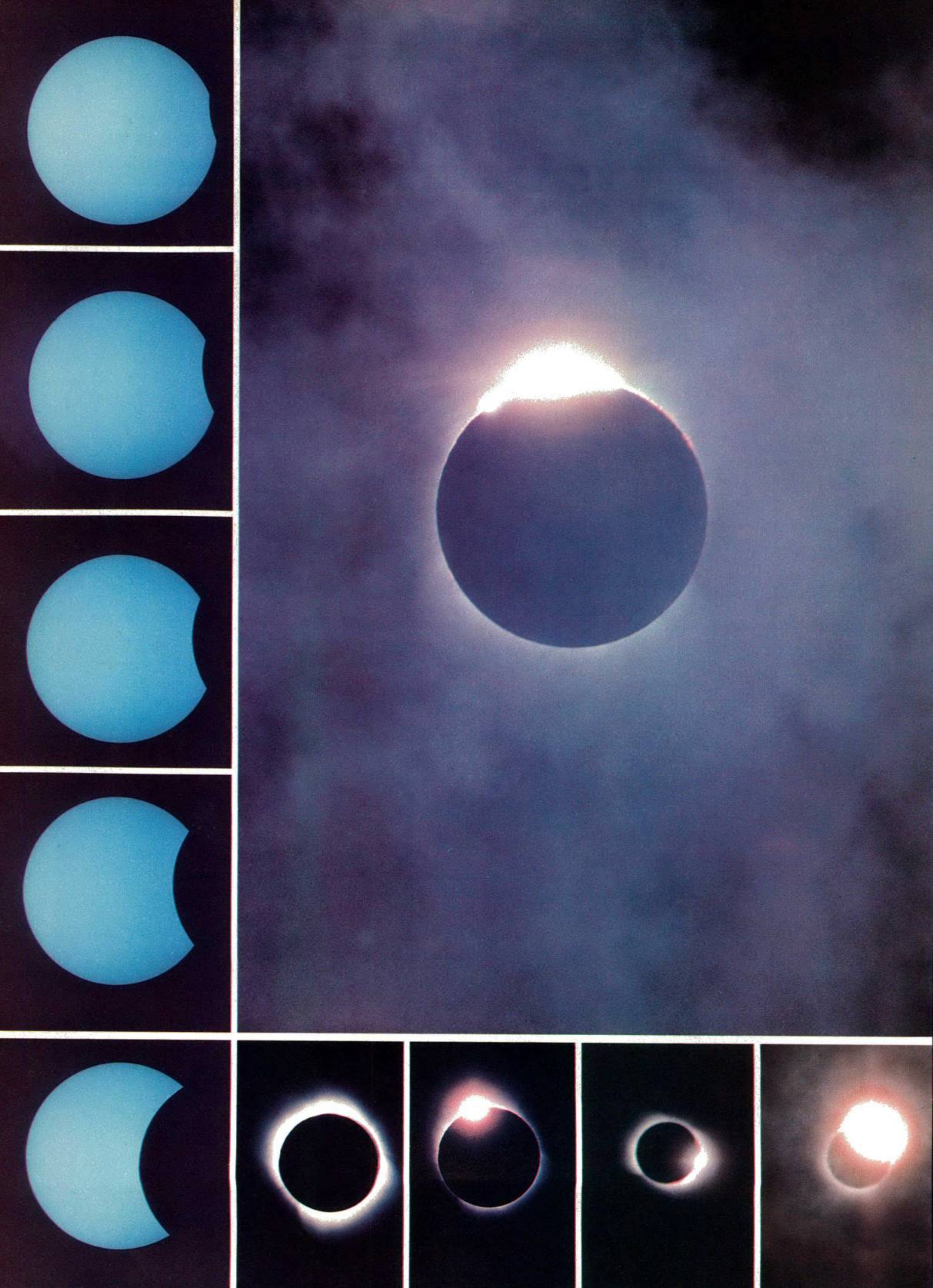
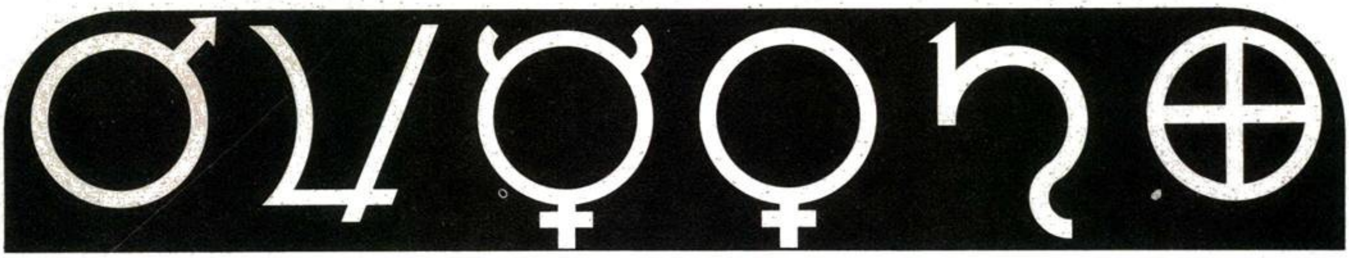




March Nights, Observers' Delight

There's a planetary bonanza for observers this month with five objects highlighting the evening skies. You can view a ringed planet, a planet with four visible moons, a red planet, the brightest, or the most elusive of the planets. Add to this the fact that spring begins this month — bringing with it a promise of warmer weather — and you have an observing opportunity that can't be beat!

Mercury

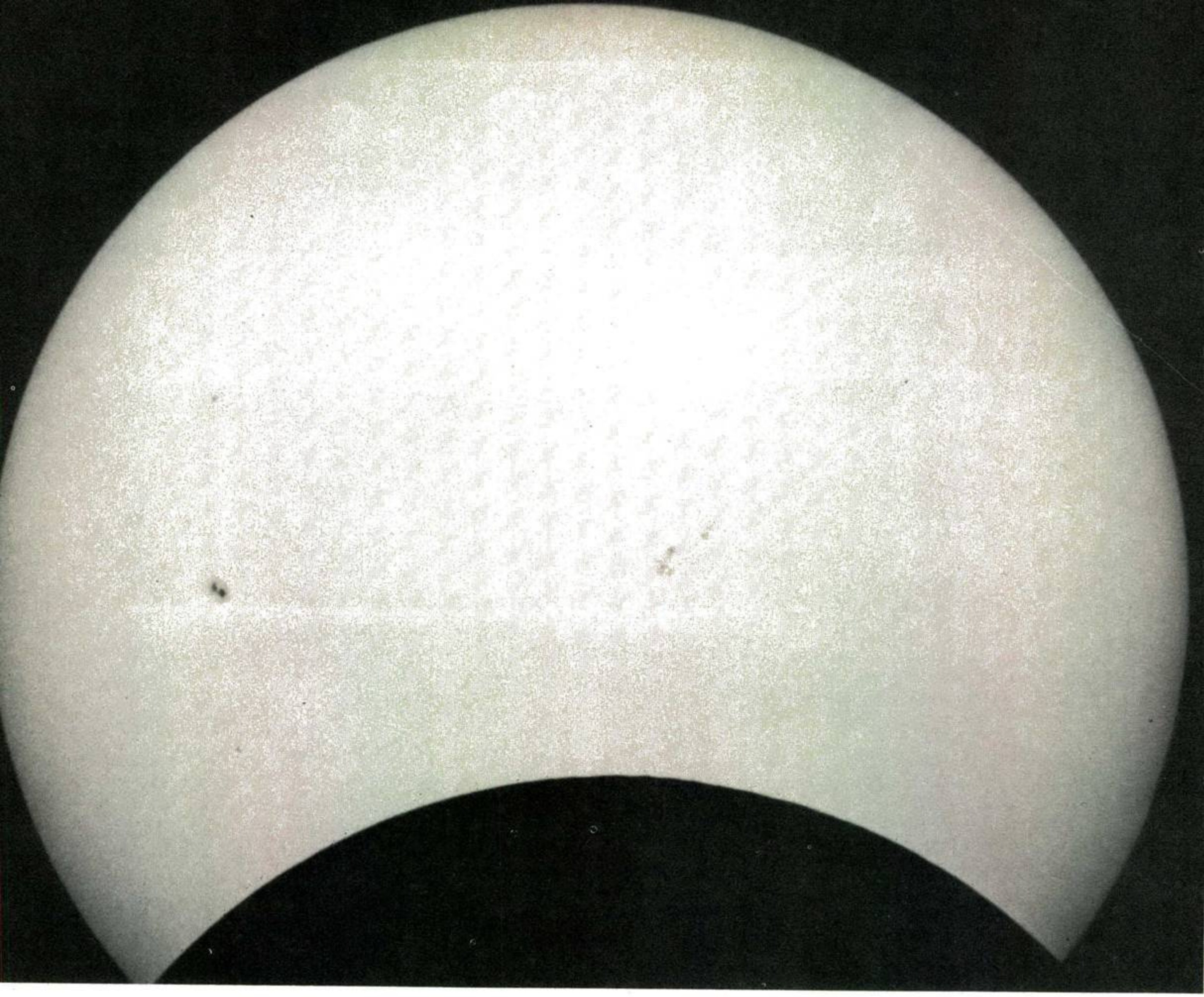
This month Mercury will be in its best position for evening viewing this year. The planet reaches greatest eastern elongation on the 24th. In other words, it will be at the farthest point in its orbit *east* of the sun, appearing in the *western* sky to the observer. A favorable elongation means that the planet will appear the maximum distance above the horizon; this

March Satellites of Jupiter
11:00 p.m. EST, 8:00 p.m. PST

1	32104	• ••● •	16	3201	• • ● •
2	32014	• • ●• •	17	31024	• •● • •
3	3024	• ● • •	18	0324	●•• •
4	10234	•●•• •	19	2034	• ● • •
5	20134	• ●• • •	20	12034	••● • •
6	1034	• ● • •	21	03124	●••• •
7	0413	●•• •	22	3104	•• ● •
8	34120	• ••●	23	32014	• • ● • •
9	34201	••• ● •	24	31024	• • ●••
10	43102	• ••● •	25	4012	• ● • •
11	4023	• ● ••	26	4203	• • ● •
12	41023	• • ●• •	27	42103	• ••● •
13	41203	• ••● •	28	40132	• ●•••
14	40312	• ●•••	29	4310	• ••●
15	3410	•• •●	30	43201	• • • ● •
			31	4310	•• •●

The four major satellites of Jupiter orbit the planet in periods ranging from less than two days to 17 days. You can see them change position from one night to the next; their motions are often evident after only a few hours' observation. You only need a small telescope to detect all four, and you can frequently make out several in rigidly held (or tripod mounted) binoculars. This table shows the approximate positions of the moons at about 11 p.m. EST on the mornings indicated. The first column on the left shows the date; the second column identifies the moons by their positions relative to Jupiter's disk (1 =Io, 2 =Europa, 3 =Ganymede, 4 =Callisto, 0 =Jupiter's disk). The third column gives the satellites' positions as they appear through a telescope. The orientation of the satellite is given with south up as seen through a standard inverting telescope.

Although the subject — the October 1977 solar eclipse — was the same, the results of each photographer's work were dramatically different. The vertical column of five pictures on the left shows a sharply defined image of the sun taken with an eight inch Celestron at prime focus with a focal reducer; Kodacolor II film was exposed for 1/1000 second at f/5. The bluish coloration comes from the double layer of Mylar solar filter screens. Photographs by Floyd Hutson. A series of four photographs comprise the bottom horizontal line. The two on the left were taken on board the ship T.S.S. Fairsea in the Pacific Ocean. Both were taken with a 3-1/4 inch refractor, focal length 610mm, on Kodachrome film. The photograph of totality was exposed for 1/15 second and the photograph of the diamond ring effect was exposed for 1/125 second. Photographs by Stephen Schiller. The remaining two photographs (bottom right) were taken on the military transport ship Usumacinto as it sailed out of the port of Manzanillo, Colima, Mexico on Oct. 10. They were taken using a 35mm camera with a 400mm telephoto lens on Kodacolor II film. Photographs by Manuel Sotomayor. The large photo in the center shows how the misfortune of cloud cover can be used to the photographer's advantage. A thin crescent of solor photosphere shows along one edge of the moon, while prominences (pink) and the solor corona have just become visible. A Rollei 2-1/4 inch camera was used with a 1200mm telephoto lens at f/11; the exposure was 1/60 second on Kodacolor II film. Photograph by Wendy Carlos.



is due to the geometry between Mercury's orbit and the tilt of Earth's axis (see Sky Almanac, April 1977).

In the beginning of the month the planet will be too close to the sun to be visible, so the best time for observing will be right around its elongation date. Look for Mercury to appear due west about 40 minutes to an hour after sunset. On the 28th you can use Venus — which will be low in the western sky — to locate the planet which will be situated approximately 10 degrees north of Venus. Mercury's distance from Earth decreases from 126 million miles (202 million kilometers) on March 1 to 69 million miles (110 million kilometers) on March 31.

If you turn your telescope toward this elusive planet, you may be able to distinguish the small, yellowish disk if the seeing is good.

Venus

Venus re-enters the planetary picture this month. At the beginning of March it will set about 45 minutes after the sun, and by month's end will be setting 1 hour 25 minutes after the sun, making it easily visible in the evening twilight. You can start looking for it early in the month low above the western horizon, where it will be shining at -3.4 magnitude.

Venus is the brightest of the planets. From March until October, it will be the brightest object in the evening sky with the obvious exception of our moon. Venus' distance from Earth decreases from 156 million miles (250 million kilometers) in the beginning of March to 150 million miles (241 million kilometers) by the end. In a telescope, it will display a nearly full gibbous disk.

Mars

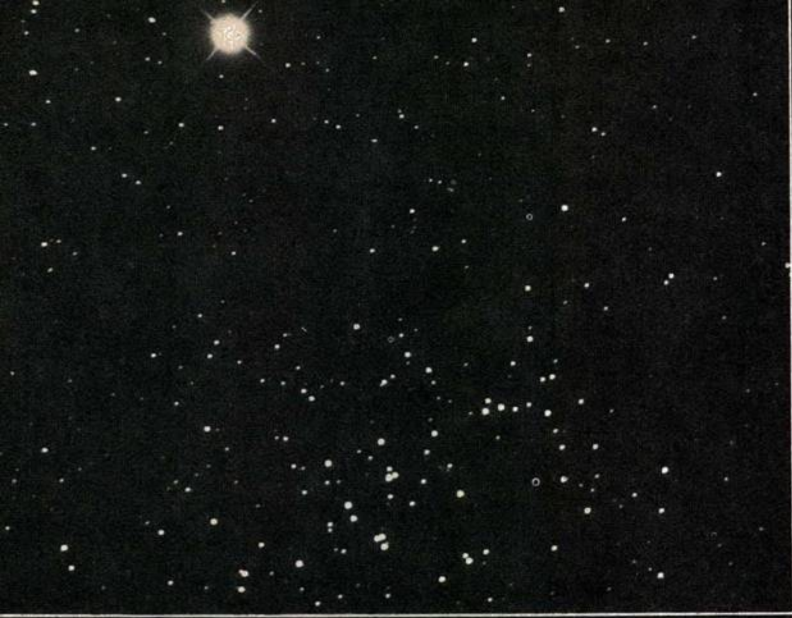
The best time for viewing Mars is early in March when it is at magnitude -0.2; by month's end its brightness will decrease to magnitude +0.5. You can find Mars high in the east southeast portion of the sky shortly after sunset. The planet is easily placed for observation all night, setting about two hours before the sun.

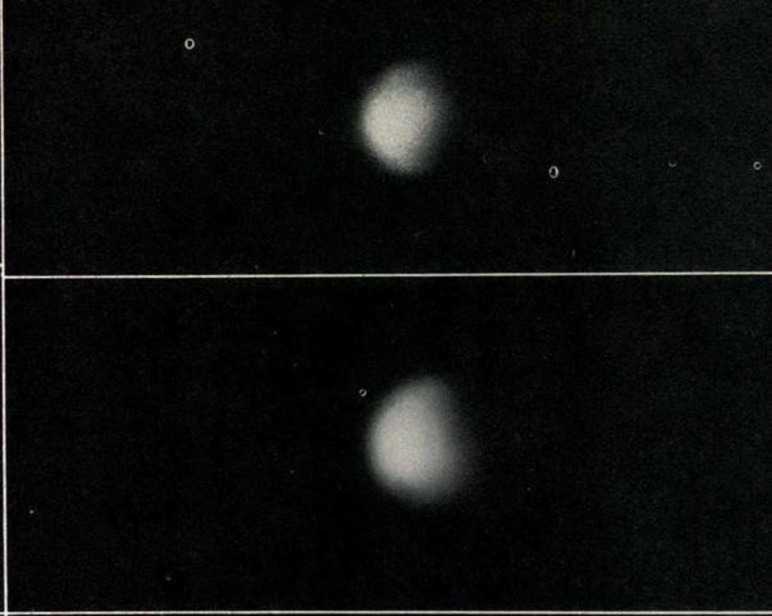
During the month, Mars moves gradually into the constellation Gemini; on the 17th you can locate the planet four degrees south of Pollux (one of the major stars of Gemini). It may be easier to find the planet on the 19th when it will be eight degrees north of the waxing gibbous (between first quarter and full) moon.

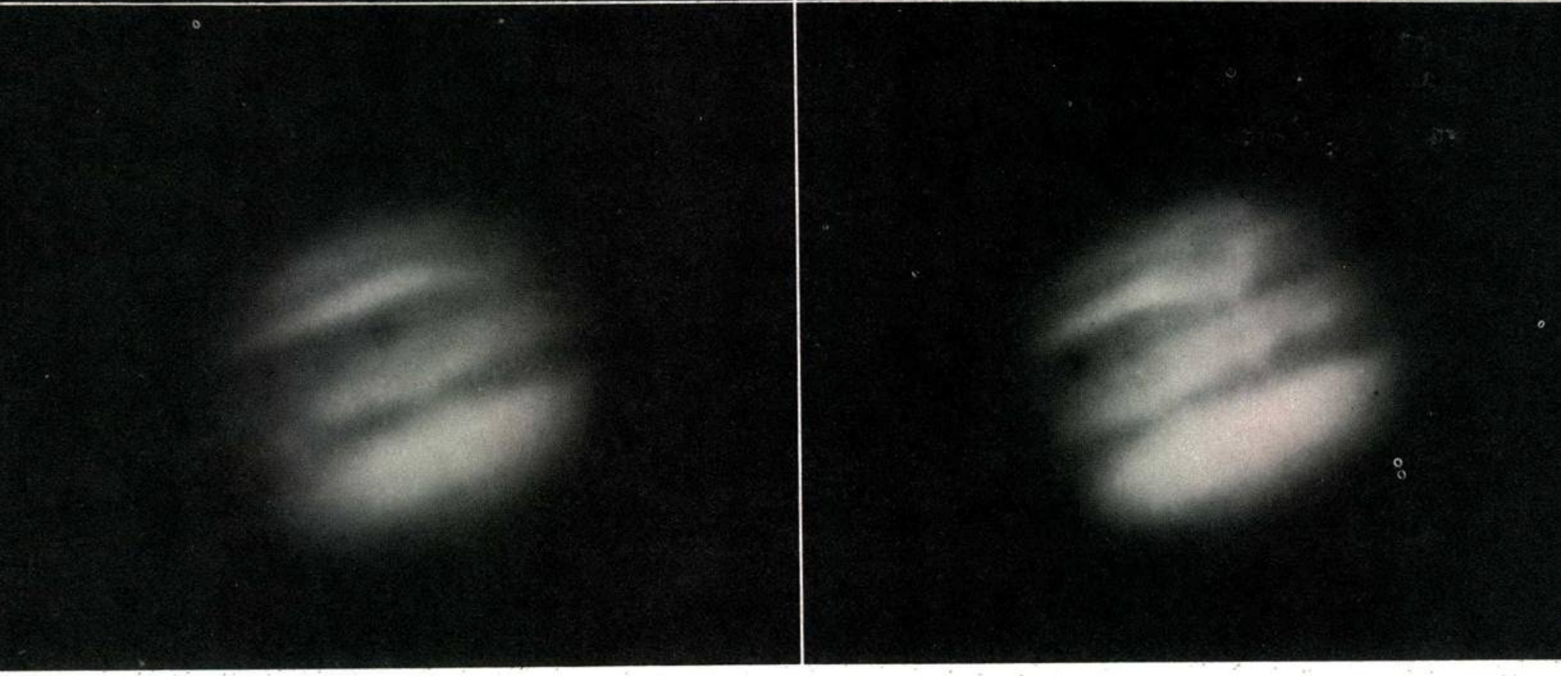
Mars' distance from Earth increases from 76 million miles (122 million kilometers) to 100 million miles (160 million kilometers) during the month. With a medium size telescope, though, you may be able to distinguish Mars' northern polar cap — a white spot on a small ochre disk.

Jupiter

This month Jupiter gives up its claim of being the brightest object in the night sky — a title it has held since last December. With the appear-







Opposite: Two groups of sunspots are visible in this shot of the Oct. 12, 1977 solar eclipse, taken with an eight inch Celestron using Panatomic X film exposed for 1/1000 second. Photograph by Kevin Sleeman. Top left: Mars is shown in the M-44 cluster in a photo taken using a six inch f/4 RFT at prime focus. Tri-X film was used for the two minute exposure. Photograph by Fred Espenak. Top and center, right: This pair of photos shows a distinctly gibbous Mars. The upper photo shows Mars with a diameter of 10-1/4 seconds of arc on Nov. 25, 1977, and the lower shows the planet with a diameter of 11-3/4 seconds on Dec. 11, 1977, growing as it approached opposition on Jan. 21 this year. The upper photograph was taken on H&W Control film and exposed for three seconds at f/126. The lower was taken on Panatomic X film and exposed for three seconds at f/154. Photographs by Lester Yuill. Bottom: These photographs of Jupiter, taken 45 minutes apart, show the shadow of its moon Io crossing the planet. Note the appearance of the famous Great Red Spot in the photo on the right. Both were taken using an eight inch f/5 reflector and exposed for eight seconds on H&W Control film with an effective focal ration of f/154. Photographs by Lester Yuill.

ance of Venus (magnitude -3.4), Jupiter — whose magnitude decreases from -2.0 to -1.8 — becomes the second brightest object visible. The planet dims gradually as its distance from Earth increases during the month from 445 million miles (713 million kilometers) to 490 million miles (784 million kilometers). At sunset the planet will be located directly overhead and will set shortly after midnight. On the 16th, look for Jupiter five degrees north of the first quarter moon. Jupiter's four large moons can be seen with large binoculars, and all telescopes will reveal their fascinating, everchanging nightly appearances.

Saturn

Saturn's distance from Earth increases from 768 million miles (1.229 million kilometers) on the 1st to 790 million miles (1,265 million kilometers) by the end of the month. The planet is gradually decreasing in brightness — from +0.4 to +0.5 during March. It will be located on the meridian (a line that passes through an observer's zenith and the north or south pole) shortly after midnight in the constellation Leo, and will set shortly before the sun.

With a small telescope you can continue to enjoy the spectacle of the rings, and the leisurely 16 day swing of Titan, Saturn's largest moon, around the planet.

Spring Arrives

Spring will officially arrive at 6:34 p.m. EST on March 20. Earth's north and south poles will then be the same distance from the sun, and the sun will be at the zenith on the equator at noon. Everywhere on Earth, the sun will rise due east and set due west. At sunset, the ecliptic (the path that the planets travel) will be at its high-

Above: Jupiter is shown in a close approach to the galactic cluster M-35 (north is to the left). A Miranda Laborec was guided on top of an eight inch RFT using a 200mm lens at f/4.5. A 10 minute exposure was made on 103aE film. Photograph by Ron Gattie. Opposite, top: This photograph beautifully illustrates the diamond ring effect that occurred during the solar eclipse of Oct. 12, 1977. Opposite, bottom: This shot shows the eclipse two seconds before totality; note the prominences and the delicate polar streamers of the solar corona. Both photographs were taken using a Rollei 2-1/4 inch camera with a 1200mm telephoto lens at f/11. Kodacolor II film was exposed for 1/60 second. Photographs by Wendy Carlos.

est placement for observers in the northern hemisphere, so planets such as Mercury and Venus will be easily visible. The vernal equinox, marking the beginning of northern spring, is the date when day and night are exactly equal in length. It *looks* like they are equal on the date, but it actually occurred three days earlier. This is due to atmospheric refraction: The sun looks like it is still above the horizon when, if Earth had no atmosphere, it would have set a few minutes earlier.

Photographs

If you'd like to submit some of your astrophotographs to ASTRONOMY but aren't sure how to go about doing so, simply drop a note to Judy O'Dair, editorial secretary, and request a copy of our Guidelines for Submitting Photographs. We'll send you one by return mail.

A note to some of our more experienced astrophotographers: Good photos of some of the lesser-known Messier or NGC objects are always in short supply at ASTRONOMY. If you submit photographs of some of these objects, they'll be good candidates for publication in some of our more specialized observing articles.

Satellite Shadows on Jupiter

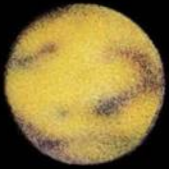
Date	Satellite	Transit Begins (EST)	Transit Ends (EST)
March 1	3	1:30 a.m.	4:33 a.m.
1-2	2	11:00 p.m.	1:30 a.m.
5	1	1:00 a.m.	3:14 a.m.
6	1	7:30 p.m.	9:43 p.m.
9	2	1:36 a.m.	4:16 a.m.
13	1	9:25 p.m.	11:38 p.m.
19	2	5:31 p.m.	8:10 p.m.
22	1	5:49 p.m.	8:03 p.m.
25-26	4	10:18 p.m.	12:27 a.m.
26	2	8:08 p.m.	10:47 p.m.
28	1	1:16 a.m.	3:30 a.m.
29	3	5:30 p.m.	8:37 p.m.
29	1	7:44 p.m.	9:59 p.m.

1 =Io
2 =Europa
3 =Ganymede
4 =Callisto

Planet Finder

Ⓒ Ceres

Mar.	1	15
R.A.	18h38m	18h56m
Dec.	-23°16'	-23°25'
Mag.	+8.1	+8.1

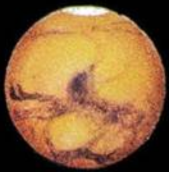


Ⓐ Mercury

Mar.	1
R.A.	22h55m
Dec.	-8°44'
Mag.	-1.4

Ⓑ Mercury

Mar.	15
R.A.	0h30m
Dec.	+3°41'
Mag.	-1.0



Ⓜ Mars

Mar.	1	15
R.A.	7h38m	7h42m
Dec.	+25°16'	+24°40'
Mag.	-0.2	+0.1

Ⓝ Neptune

Mar.	15
R.A.	17h09m
Dec.	-21°28'
Mag.	+7.7

SUN

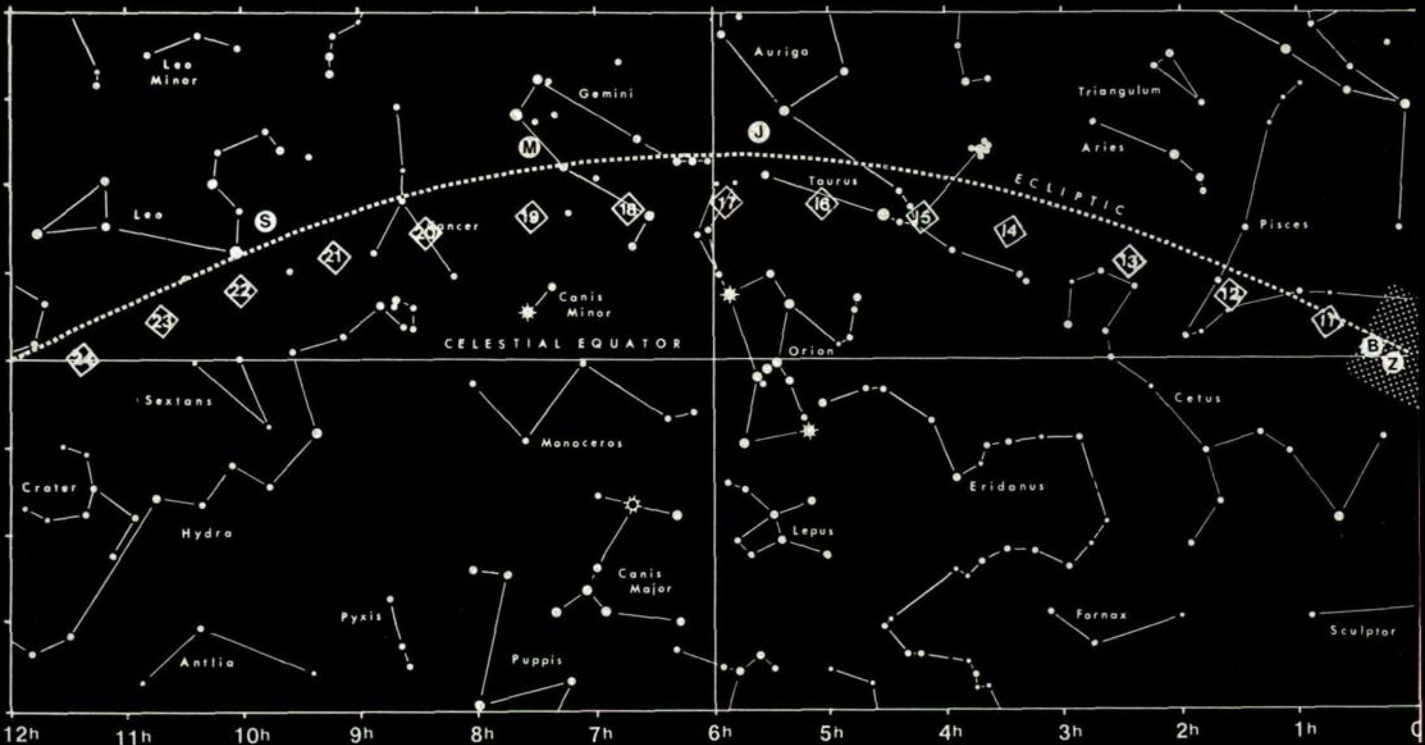
The sun is within the stippled zone throughout the month. Planets and stars near this area are not easily seen.

Ⓢ Saturn

Mar.	1	15
R.A.	9h55m	9h51m
Dec.	+14°16'	+14°37'
Mag.	+0.3	+0.4

Ⓤ Uranus

Mar.	15
R.A.	14h55m
Dec.	-16°17'
Mag.	+5.7


Leo Minor
Gemini
Auriga
Triangulum
Aries
J
M
Taurus
ECLIPTIC
Leo
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Cancer
Pisces
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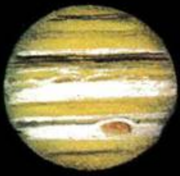
24
Canis Minor
CELESTIAL EQUATOR
Orion
B
Z
Sextans
Cetus
Monoceros
Crater
Eridanus
Hydra
Lepus
Canis Major
Pyxis
Fornax
Sculptor
Antlia
Puppis
12h
11h
10h
9h
8h
7h
6h
5h
4h
3h
2h
1h

The chart shows the positions of the moon, planets and brightest asteroids for the current month. Letters within the circles correspond to the letters beside each object in the data section above the map. Additional information about each object is given there. R.A. = right ascension and Dec . = declination, the two coordinates used to locate astronomical objects. The general coordinate system is indicated around the edge of the map. Mag . = magnitude, a

March 1978

Ⓥ Vesta

Mar.	1	15
R.A.	16^h36^m	16^h54^m
Dec.	-14°58'	-15°13'
Mag.	+6.7	+6.5



Ⓙ Jupiter

Mar.	1	15
R.A.	5^h43^m	5^h46^m
Dec.	+23°18'	+23°21'
Mag.	-2.0	-1.9

ⓎVenus

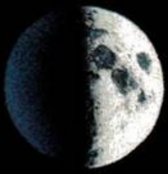
Mar.	1
R.A.	23^h22^m
Dec.	-5°35'
Mag.	-3.4

ⓏVenus

Mar.	15
R.A.	0^h26^m
Dec.	+1°32'
Mag.	-3.4

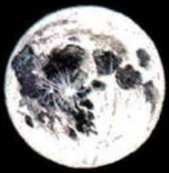
Ⓟ Pluto

Mar.	15
R.A.	13^h24^m
Dec.	+10°09'
Mag.	+14



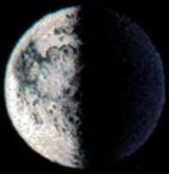
First Quarter

March 16



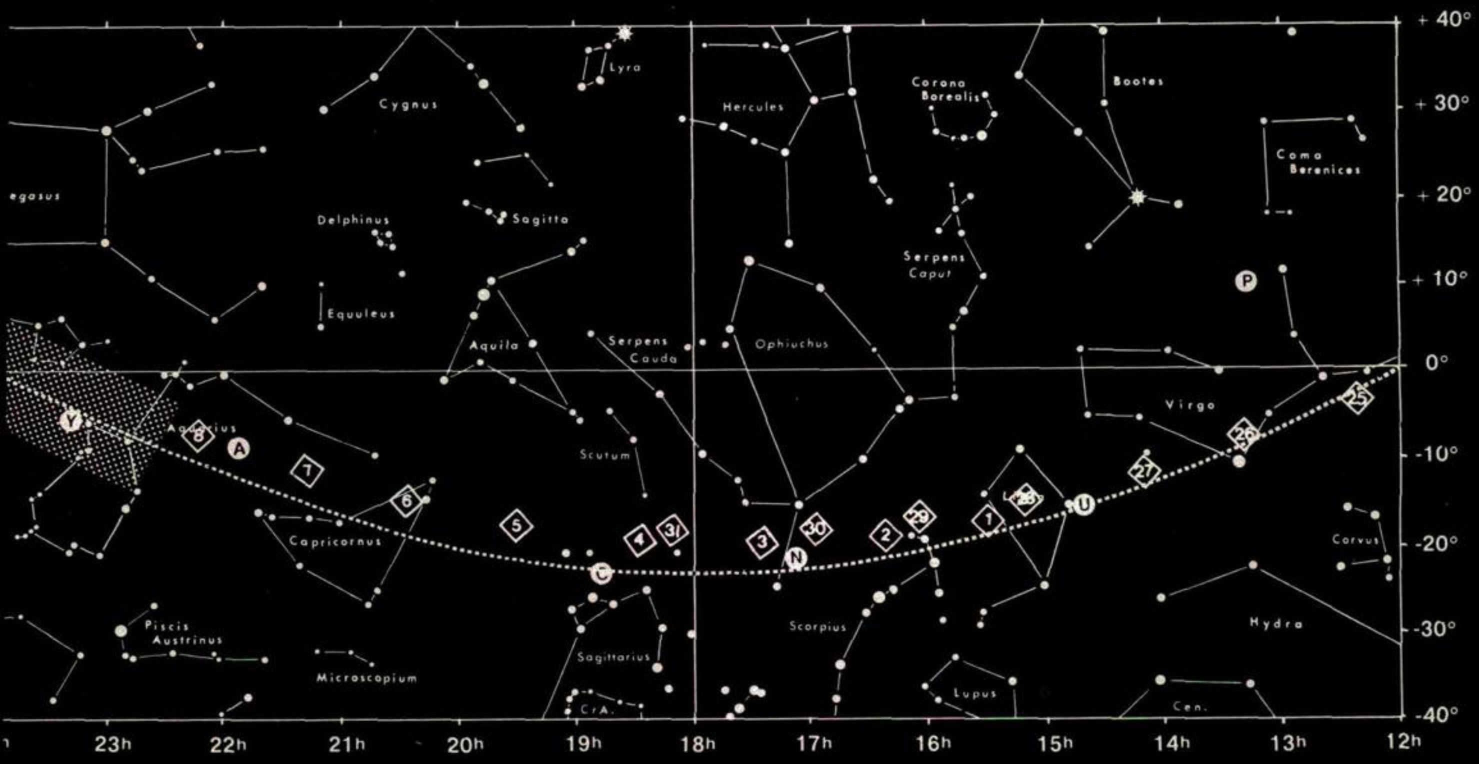
Full Moon

March 24



Last Quarter

March 2
March 31



+ 40°
+ 30°
+ 20°
+ 10°
0°
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19h
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Lyra
Cygnus
Hercules
Corona Borealis
Bootes
Coma Berenices
egasus
Delphinus
Sagitta
Serpens Caput
Equuleus
Aquila
Serpens Cauda
Ophiuchus
Aquarius
Scutum
Virgo
Libra
Capricornus
Corvus
Piscis Austrinus
Sagittarius
Scorpius
Hydra
Microscopium
CrA.
Lupus
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25

measurement of the object's brightness. (The minus magnitudes indicate very bright planets.) The diamonds with numbers within them indicate the position of the moon for each day of the month; the numbers correspond to the dates. Positions of the planets are for the 15th of the month except for Mercury and Venus which are shown on both the 1st and 15th. Certain areas of this map and the Star Dome chart overlap each month.

SPACE 1978

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ASTRONOMY magazine proudly presents SPACE 1978 — an exciting new art and photography calendar depicting the awesome beauty of space and astronomy in vivid breathtaking color.

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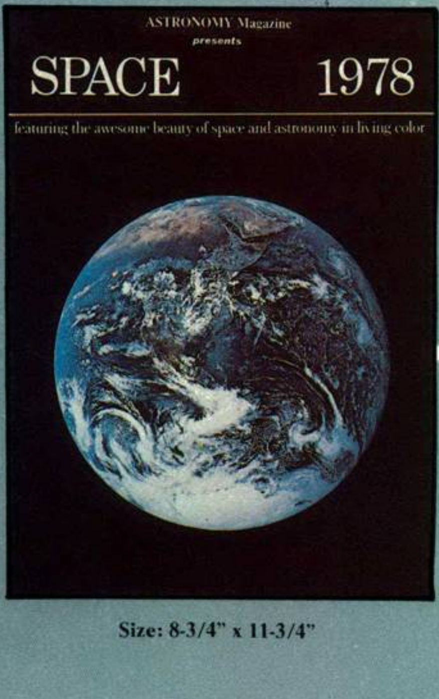
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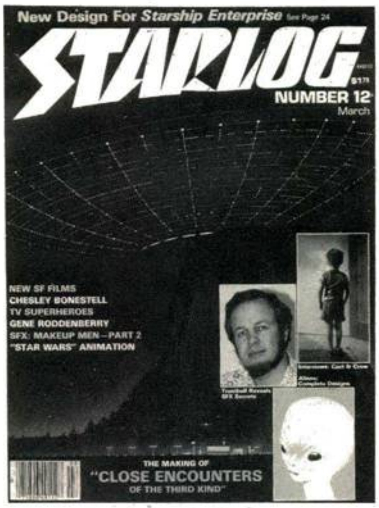
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STARLOG
NUMBER 12
March
NEW SF FILMS
CHESLEY BONESTELL
TV SUPERHEROES
GENE RODDENBERRY
SFX: MAKEUP MEN—PART 2
"STAR WARS" ANIMATION
THE MAKING OF
"CLOSE ENCOUNTERS
OF THE THIRD KIND"

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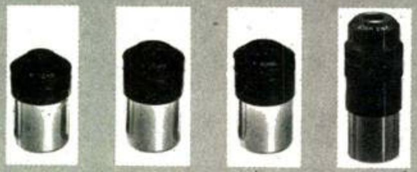

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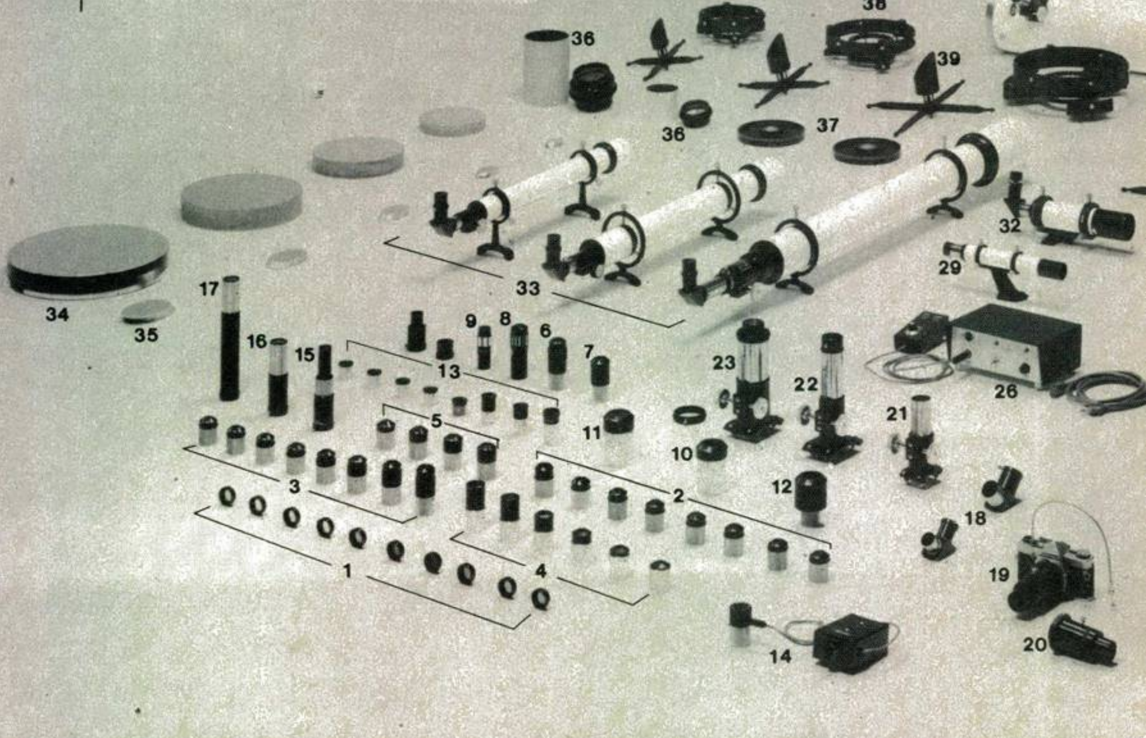

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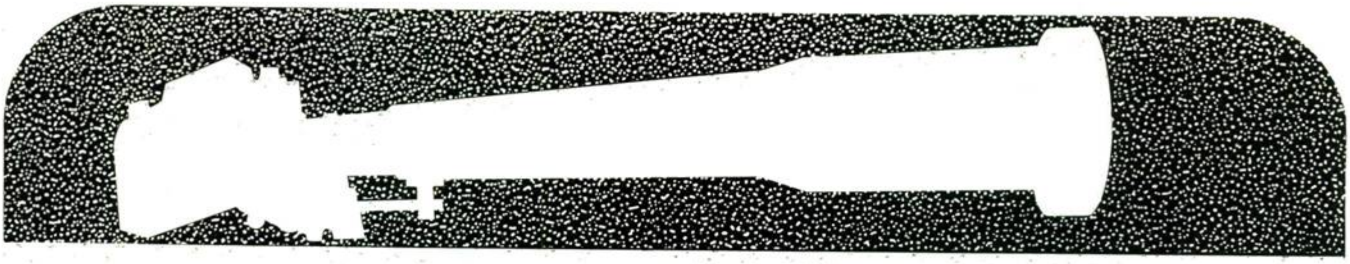


PHOTOGRAPHY IN ASTRONOMY

Isophote Mapping

by
Fred Espenak

One hundred fifty years after its invention, photography remains the astronomer's most powerful detector, as well as one of man's most universal forms of communication. Everybody knows the old cliche "a picture is worth 1,000 words", but have you ever thought what an understatement it is? The typical black and white emulsion capable of resolving 100 lines per millimeter carries some 10 million bits of information on each one of your 24x36mm negatives! The information is stored in the form of its position on the negative and the density or concentration of silver grains at that point. When you make an enlargement from this negative, the print generally retains most of the positional information contained in the negative but loses much of the density information. Fortunately, there are a number of *image enhancement techniques* which can be performed with nothing more exotic than a basic black and white darkroom. One of these techniques is known as *isophote mapping*.

An *isophote* is a contour of equal intensity. In producing an isophote map, the continuous range of density information contained in the original negative is broken down into a series of steps. Since density and intensity are related by the characteristic curve, each interval represents a specific range of light intensities seen in the original subject. You can think of an isophote map as a topographic contour map for light intensity rather than elevation.

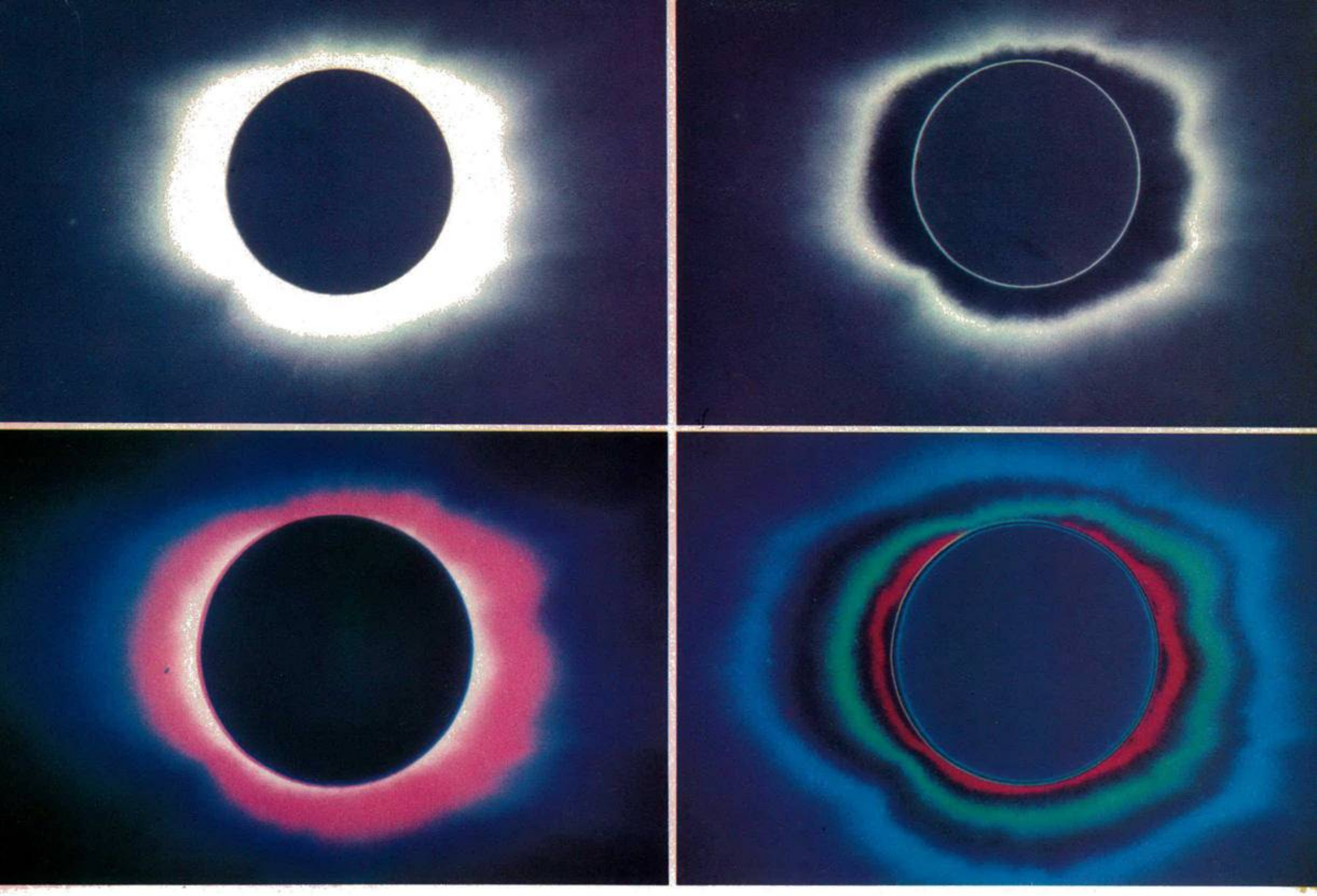
Sabattier Effect Isophote Maps

How can you actually go about making an isophote map from an ordinary negative? One trick is to use the Sabattier effect. The *Sabattier effect* is the process of *solarizing* a photographic printing paper during development. The print you'll get isolates one narrow density range while rendering all other densities black.

In addition to normal darkroom equipment, you'll need: *1)* high contrast enlarging paper (Kodabromide grade 5 or Agfa Brovira grade 6), *2)* an empty developing tray, *3)* a pair of C clamps, *4)* a pair of registration pins, *5)* a two hole office punch, *6)* a copy stand and *7)* a 7-1/2 watt light bulb and fixture for it. The fixture should consist of an insulated socket on the end of a six foot cord, equipped with a switch and wall plug. It can be purchased along with the C clamps at a hardware or hobby store. The light bulb should be held suspended about three feet above your empty developing tray. One simple solution is to hang the bulb off the end of your enlarger table and place the trays underneath it on the floor. A set of six registration pins (size 0-3) can be purchased from Bregman Co., 1211 Anderson Ave., Fort Lee, N.J. 07024 for $4, and the hole punch (1/4 inch holes) is available in an office supplies store.

You'll also need to build a special *registration easel* consisting of a 10x12 inch piece of masonite and two registration pins. Epoxy the pins along one edge of the masonite with a spacing between them equal to that of the two hole office punch; the best way to do this is to punch a pair of holes in an index card and use it to position the pins. The C clamps should be used to rigidly hold your registration easel to the baseboard of your enlarger. This allows you to achieve perfect alignment between successive prints you will make.

When making your prints, be sure to first clean the negative and carefully place it in the enlarger. Adjust the enlarger for the desired magnification and focus carefully. Next, make a test strip and develop in the usual manner. Select the exposure which renders the clearest part of your negative a



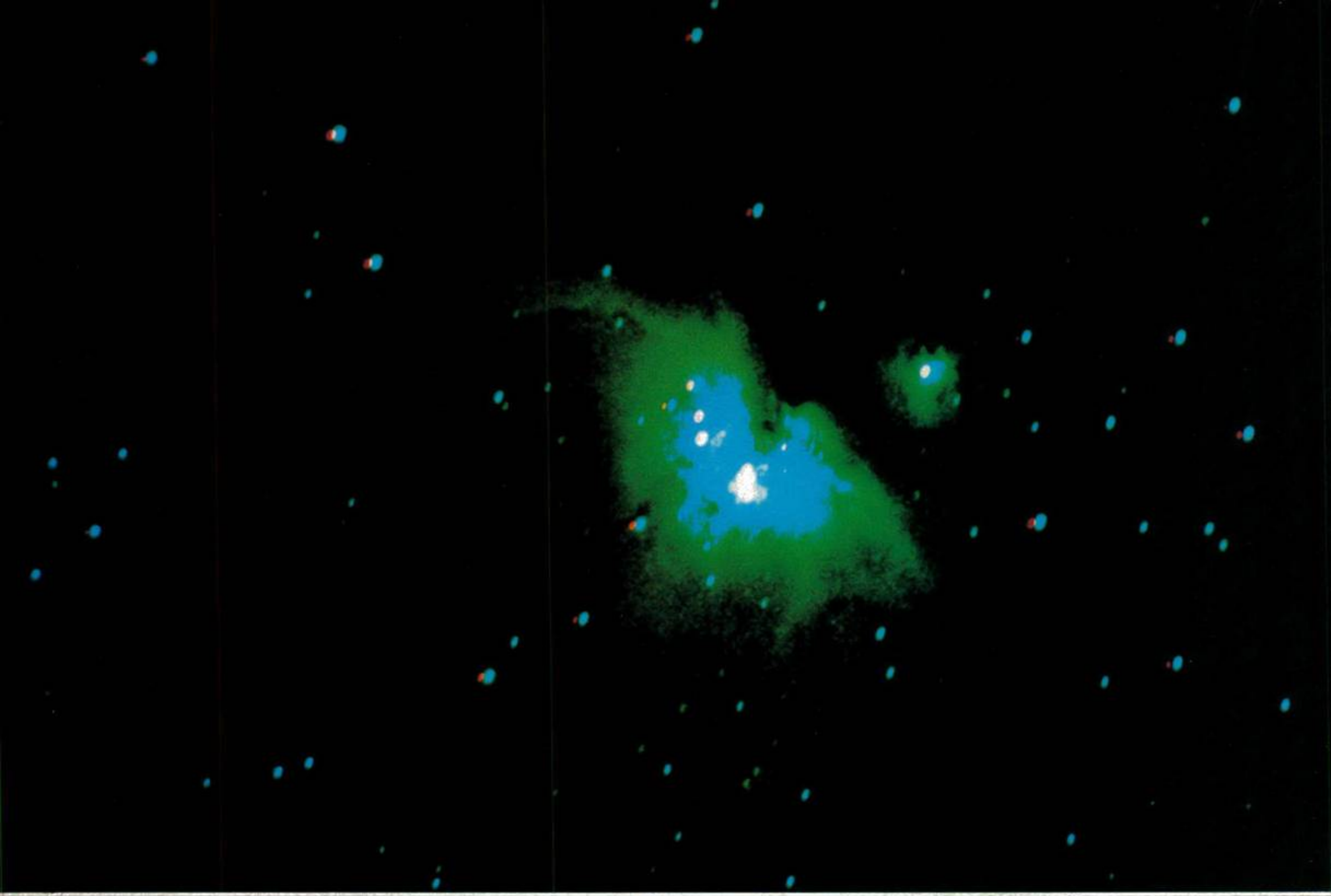
Upper left: Isophote images begin as ordinary black and white prints on high contrast paper — in this case, a photograph of the solar corona taken on Plus-X film with a 400mm telephoto lens on June 30, 1973. Upper right: When an ordinary print is "flashed" with light during development, an isophote contour appears. Lower left: By copying three normal black and white prints made from the same negative onto color film through color filters, you can make a false color image. The outer corona was copied with a blue filter, the middle corona with a red filter (blue + red = magenta), and the inner corona with a green filter (blue + red + green = white). Lower right: By copying three isophote prints made from one negative, you can produce a color isophote image. Each isophote identifies a different intensity zone in the corona. Photographs by Fred Espenak.

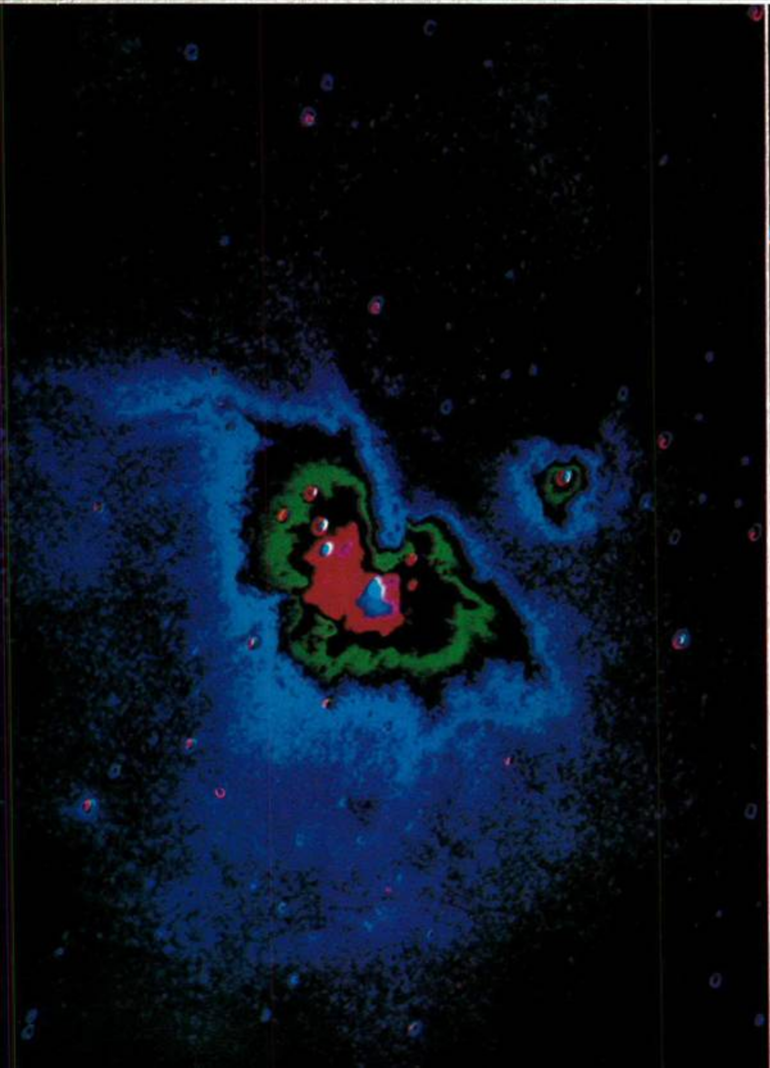
dark gray. This will serve as your trial exposure in achieving the Sabattier effect.

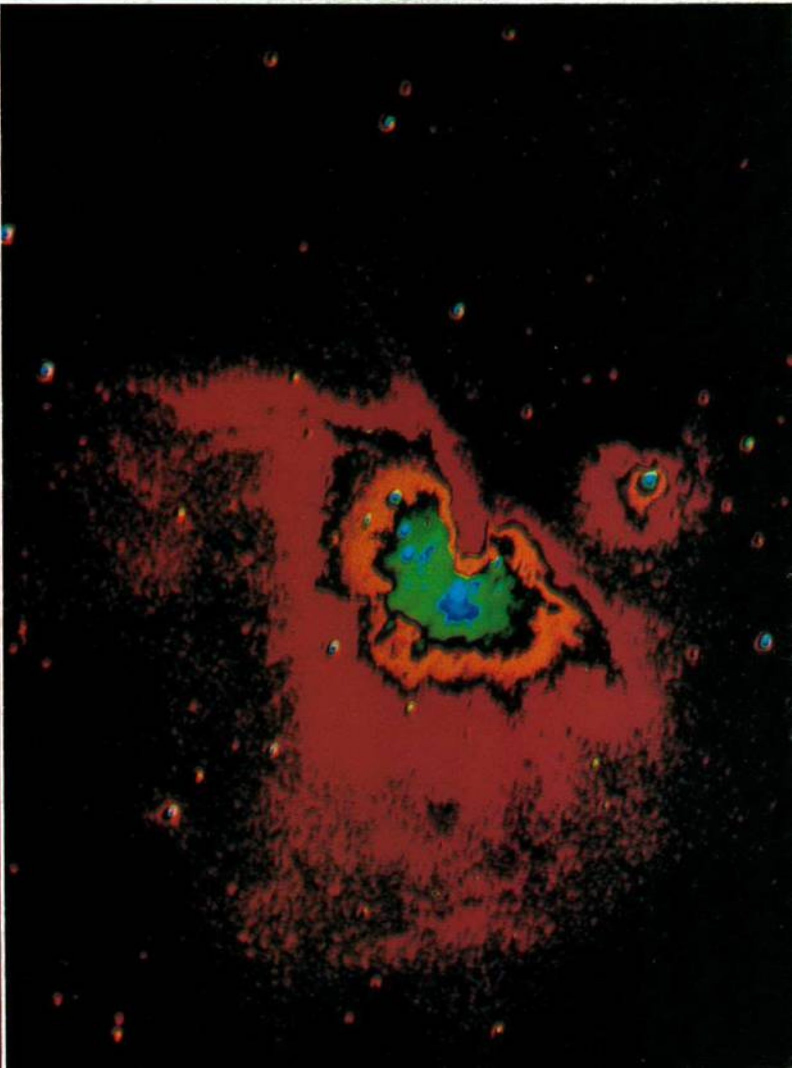
Next, punch a pair of holes in a piece of enlarging paper and mount it on the registration board. Make an exposure using the previously determined time and place the paper in the developer. Develop the print for only 1/2 the required time. Kodak Dektol (1:2) normally requires two minutes at 20 degrees Centigrade (68 degrees Fahrenheit), so you would remove the print after 60 seconds of development. Quickly transfer the print to the empty tray, emulsion side up, and rinse with water. *Do not use stop bath!* Put the tray under your 7-1/2 watt bulb and place a piece of cardboard across the top of the tray so that it covers 4/5 of your print. Turn the bulb on and flash the print with a two second exposure. Now slide the cardboard covering the tray so that another 1/5 of the print is uncovered. Give the print another two second exposure. Repeat the process until the entire print is uncovered and has been exposed to the bulb. Return the print to the developer to complete the full development time (in this case another 60 seconds). Fix and wash the print as usual.

The resulting print will now serve as a test strip for the Sabattier effect using your particular negative, printing paper and developer combination. As you look at your test strip, it will be broken up into five zones which received 2, 4, 6, 8 and 10 seconds respectively of re-exposure after partial development. The Sabattier effect is capable of producing a variety of images from one negative, but we are interested in making isophotes. To determine the proper flash time, therefore, choose the zone which rendered the normally white areas of the print as black and produced a pale gray border around them. Photographers refer to these borders as Mackie lines, but they are also isophotes.

How does the characteristic curve explain this strange image? Upon partial development, many of the silver halide grains have already been converted to metallic silver (black areas) and are on the shoulder section. Upon re-exposure, nothing much happens to these areas because there is little silver halide left to react. The white areas of the print, however, are loaded with silver halide grains. The second







exposure moves these areas from the toe to the shoulder section and they turn black during completion of development. The gray areas (logarithmic section) of the print also contain silver halide grains and re-exposure throws them up over the shoulder and onto the Sabattier effect section. Therefore, they only darken slightly with further development.

Finally, make a print using the experimentally determined re-exposure time. The resulting image will be a map displaying a narrow range of the densities present in the original negative. Different density values from the negative can be isolated simply by using a different initial exposure on the print while maintaining the same flash exposure time. Try making isophote maps using two, four and eight times the normal printing exposure, being careful not to touch the enlarger or adjust the focus. You will end up with a set of four maps, each of which will isolate one density area of the negative.

Creating Isophote Maps

The next step of the process is to rephotograph each of the four isophote maps onto the same frame of film. This is where exact registration comes in. You will need a copy stand which can easily be built (see Petersen's **Darkroom Equipment You Can Build Yourself**), if you don't already own one. Some enlargers can serve as copy stands if the head can be replaced with your 35mm single lens reflex camera. Bolt your registration easel to the base of the copy stand using the C clamps and place one of your isophotes on the easel. Load your camera with a medium speed (ASA 100 to 125) black and white film, mount it on the copy stand and adjust the camera so that the isophote print fills the frame of the viewfinder. Your light source can be either photo flood lamps or indirect sunlight, but check that neither makes a glaring reflection off the isophote print. Take a meter reading off a Kodak 18 percent reflectance target or a piece of gray cardboard to determine the proper exposure.

You're now ready to combine all four isophote images into one map through multiple exposure. If your 35mm does not have a special provision for multiple exposures, you can operate it as follows (but first refer to your camera manual): After making the first exposure, turn the rewind crank clockwise to take in the slack. Hold the rewind crank in this position with your thumb and wrap your hand around the camera so that you can depress the rewind button on the bottom with one of your fingers. While holding the crank and depressing the botton, wind the film advance lever with your free hand. You have just cocked the camera shutter without advancing the film. Using this procedure, photograph all four isophote prints sequentially onto the same film frame. Be very careful not to disturb the orientation of the camera and to correctly position the registration holes of each isophote picture onto the pins on your registration easel. A shift in either of these will produce misalignment between the isophote images.

The final result will be one isophote map which displays four different density ranges found in the original negative. The technique is a powerful one and is especially suited to extended objects such as nebulae and galaxies. Once you've mastered the process, you might try making isophote maps on color film, using a different color filter over the camera lens to copy each isophote. In any case, isophote maps have a beauty all their own.

Top: This false color photograph of M-42 was made by copying three Kodalith film positives of the inner (bright), middle and outer regions of the Orion nebula through a green, a blue (green + blue = cyan), and a red (green + blue + red = white) filter, respectively. The resulting photograph strongly resembles the visual appearance of the nebula in a medium size telescope. Bottom, left and right: Isophote maps of the Orion nebula were made by photographing pairs of Kodalith positives and negatives through color filters. Note the colorful variations possible. Photographs by Fred Espenak.

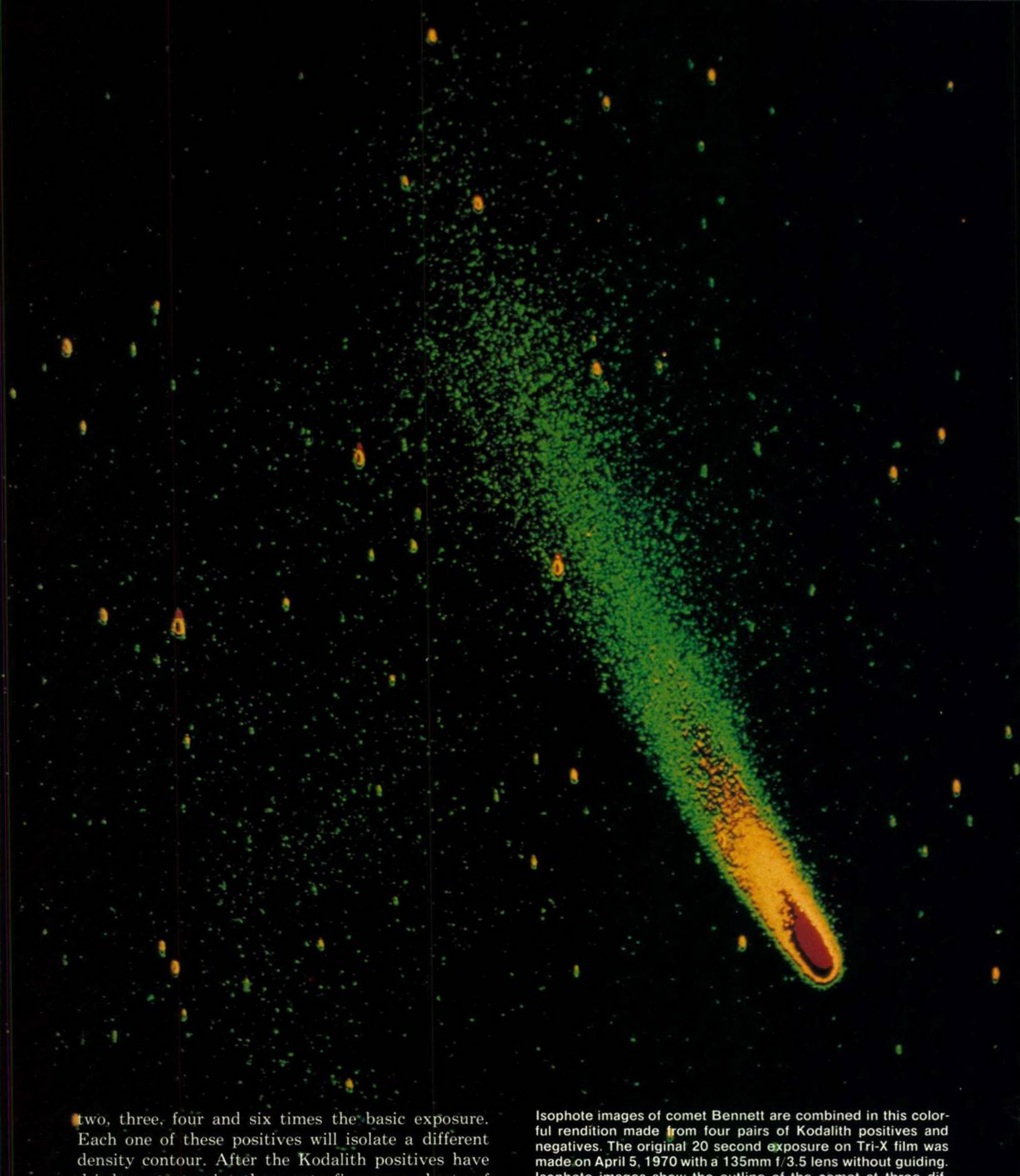
Lithographic Film Isophote Maps

Another method of producing isophote maps requires the use of a group of materials known collectively as *lithographic film*. The primary characteristic of lith film is its ability to produce images of extremely high contrast. It essentially reproduces a continuous tone negative in terms of black and white, completely eliminating all the gray tones. If you look at the characteristic curve for a lithographic film, you'll find that the logarithmic section is almost vertical.

Such a harsh material is tricky to work with, but it does have its advantages. For one thing, isophote maps can be made directly in the darkroom without rephotographing the individual images produced using the Sabattier effect. Another is that the isophote maps made using lith film have sharper, narrower isophotes and more of them can be combined into one map.

Lithographic films are manufactured by several companies, but the type made by Kodak (Kodalith Ortho Film #2556, type 3) is most widely available. It comes in 35mm rolls of 100 feet (as type #6556), but the 4x5 or 5x7 film sizes are much more convenient to work with. Kodalith is an *orthochromatic material*, which means you can work with it using a red safelight. Kodak makes a special Kodalith developer (parts A and B), but Dektol can be substituted with some loss of contrast.

The key to making isophote maps using Kodalith is to first produce a set of density separations from the original negative. In the dark, punch a pair of holes in a sheet of Kodalith, place it on the registration easel (emulsion side up) and make a test strip. Develop, fix and wash the test strip, and select the shortest exposure required to print a clear section of the negative as black on the Kodalith. This exposure will reveal the outermost parts of nebulae, comets and galaxies, or it will accent features along the moon's terminator. Make a set of five Kodalith positives using exposures of one,



two, three, four and six times the basic exposure. Each one of these positives will isolate a different density contour. After the Kodalith positives have dried, contact print them onto five more sheets of Kodalith, using the registration easel and your enlarger as the light source. You now possess a set of five positive/negative matched pairs which can be labeled as A, B, C, D and E. Primes (A', B', C', D' and E') will be used to denote the negative Kodaliths.

Isophote images of comet Bennett are combined in this colorful rendition made from four pairs of Kodalith positives and negatives. The original 20 second exposure on Tri-X film was made on April 5, 1970 with a 135mm f/3.5 lens without guiding. Isophote images show the outline of the comet at three different brightness levels, including such features as the division of the inner tail. Photograph by Fred Espenak.

The Kodalith density separations can be used to produce a variety of effects. You will notice that if you superimpose B' on A (negative B on

The Photographic Process

Photographic emulsions consist of a finite number of extremely tiny (10^{-3}mm), light sensitive chemical grains suspended in a transparent gelatin and supported by a glass plate or plastic base. The light sensitive grains are composed of crystals of silver halogen compounds, often referred to as silver halides. When photons (packets of light energy) strike a silver halide crystal, electrons are released from it at a rate proportional to the number of photons (the intensity of illumination). The free electrons don't travel very far in the grain before they stop and are captured by a positively charged silver ion, resulting in a neutralized silver atom. These silver atoms form a *latent image* and act as catalysts during development, inducing all the silver halide crystals in the same grain to reduce to metallic silver. When you fix emulsion, all the remaining silver halide grains are dissolved, leaving behind a pattern of metallic silver grains whose positions form an integral record of where light fell on the film. The number of silver grains per unit area is proportional to the intensity of light which struck that area. When you look at the negative, the silver grains prevent light from passing through. The density or ability to transmit light at any point on the negative, therefore, gives us information which characterizes the intensity of the light which formed our image.

In order to relate the intensity of light which struck the emulsion to the corresponding density of the resulting negative, astronomers plot what is referred to as the characteristic curve for the emulsion. The characteristic curve is usually divided into three sections: the *toe*, the *logarithmic section* and the *shoulder*. In photographing an object, it's best to use an exposure which will produce a range of densities on the logarithmic section. If you underexpose, you're using the toe section, so the negative will be very transparent because not enough light was available in the conversion of silver halides to silver. With overexposure, the negative will be very dark since most of the silver halides have been converted to silver. This is the shoulder region of the characteristic curve. Photographic emulsions cannot produce an infinite range of densities because they don't contain an infinite number of grains. This explains why the characteristic curve becomes horizontal in the toe and shoulder sections.

When the photographic emulsion is subjected to extremely intense exposure, a very curious and complex reaction takes place. The characteristic curve begins to bend downward and the negative starts to act like a positive. This phenomenon is known as solarization.

In making a print, you usually use an enlarger to project an image of the negative onto a piece of paper which has also been coated with silver halide grains suspended in gelatin. The paper is then developed and fixed just like the negative was. The resultant print now displays some of the negative's density information; however, where a negative stores density information over a range of 500 to 1, a print drastically compresses this range to just 30 to 1. In other words, the whitest areas of the print reflect only 30 times as much light as the blackest areas, greatly reducing the dynamic range of the negative. Printing paper is said to have a much narrower *latitude* than film — it just isn't capable of reproducing subtle differences found on the original negative. In real terms, this means that when you print a picture of M-42, you can either make an exposure which shows the central Trapezium stars or one which shows the extensive nebulosity surrounding it. To make a print which shows both features is beyond the range that printing papers can display without employing a specialized technique.

positive A), you have an isophote. To produce an isphote map in the darkroom, first determine the proper exposure time to contact print one of the Kodalith negatives onto a piece of high contrast enlarging paper. Next, punch a pair of holes in a piece of enlarging paper and contact print the following Kodaliths onto it: A' (by itself), and the combinations BC' and DE'. The resulting print will have two isophotes. More isophotes can be produced by making more Kodalith separations from the original negative.

Color isophote maps from the Kodalith separations are possible using a *light table* clamped to your copy stand. The light table must be modified by taping two registration pins to it in order to achieve perfect alignment between Kodaliths. When the Kodaliths are arranged in pairs (for example, AB', CD', EF'), each pair can be rephotographed through color filters in the same manner used to make the Sabattier isophote maps (see the photographs on pages 44 and 46).

Additional techniques can be found in books like Petersen's **Photographics** and **Guide to Creative Darkroom Techniques.**

Other Possibilities

A variation on the color isophote map can be made which eliminates the black bands between adjacent isophotes. The effect is popularly known as *posterization* and can be achieved by rephotographing more closely spaced Kodalith pairs through different color filters (AB', BC', CD' and DE'). This technique is very effective on objects whose surface brightness changes very rapidly. The moon is a good example (see the photograph on the cover).

You'll get still another effect when you photograph three Kodalith positives which isolate different densities (such as A, D and F) through three color filters. The resulting false color photograph can bear a remarkable resemblance to the original subject if the colors of the filters are suitably chosen.

These are just a few of the possibilities available if you want to squeeze the most out of your negatives. Study the examples in this article, and then get started on your own isophotes. There's a lot more in those negatives than first meets the eye!

Fred Espenak works for Computer Sciences Corp. as a computer analyst at Goddard Space Flight Center in Greenbelt, Md. At the time this article was written, he was training to be a telescope operator for NASA's International Ultraviolet Explorer satellite which was scheduled for launch in January.

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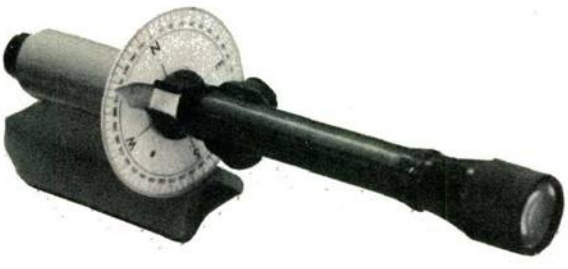

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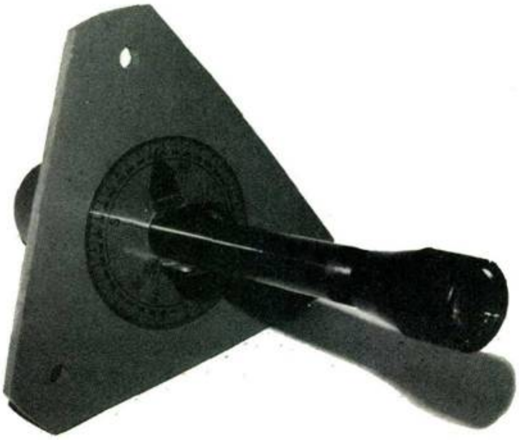

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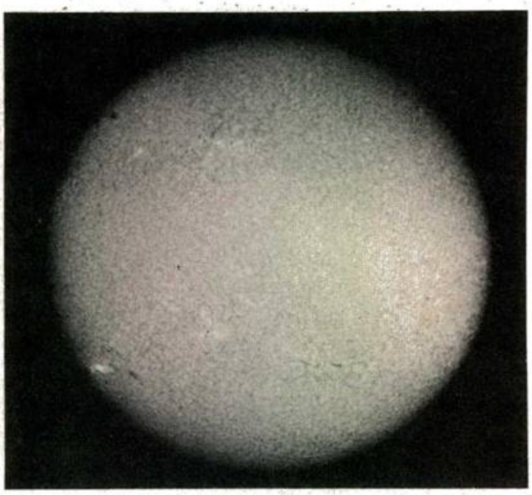
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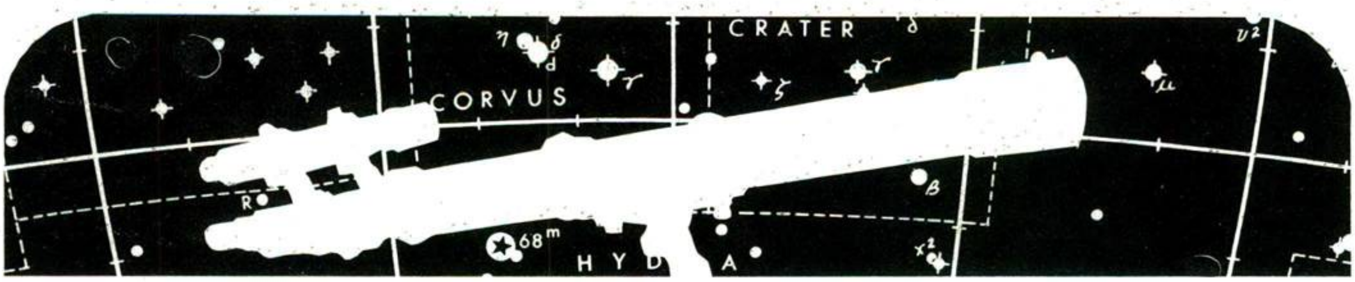


EQUIPMENT ATLAS

What's Inside Your Telescope?

Part I: Refractors

by
Robert E. Cox

If you've just bought a telescope, you may wonder what's inside and how it works. You aren't alone. Many people who observe the heavens purchase their telescope and often can't find instructions or information about it! And parents who give a teenager or child a telescope for Christmas or birthdays soon find they must answer the question, "What's inside my telescope?"

A telescope maker knows what's inside his instrument because he built it — but the parent, child or novice astronomer is not so fortunate. In this series of articles, therefore, ASTRONOMY will show you what is inside the telescopes used in the hobby of astronomy. And if you're considering making your own instrument — either from a kit or by assembling components after purchasing them from one or more of the suppliers who advertise such wares — you'll want to read on!

All telescopes are composed of two basic types of optical elements, active and passive in their function. *Active elements* are those which contribute to the formation of the final image. They generally have curved surfaces. *Passive elements*, which do not contribute a definite power to the image, generally have a flat or plane surface. We must stress that a low quality passive element can cause serious degradation of a final image. Basically, all the elements — either active or passive — must be of the highest optical quality in an astronomical telescope.

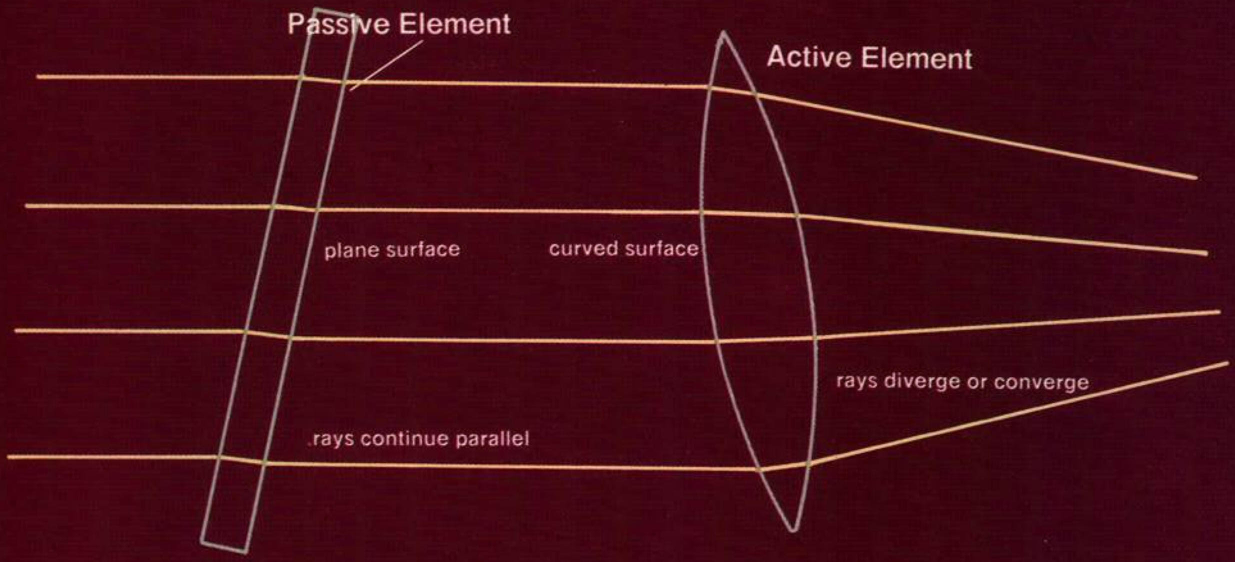
The Dioptric Telescope

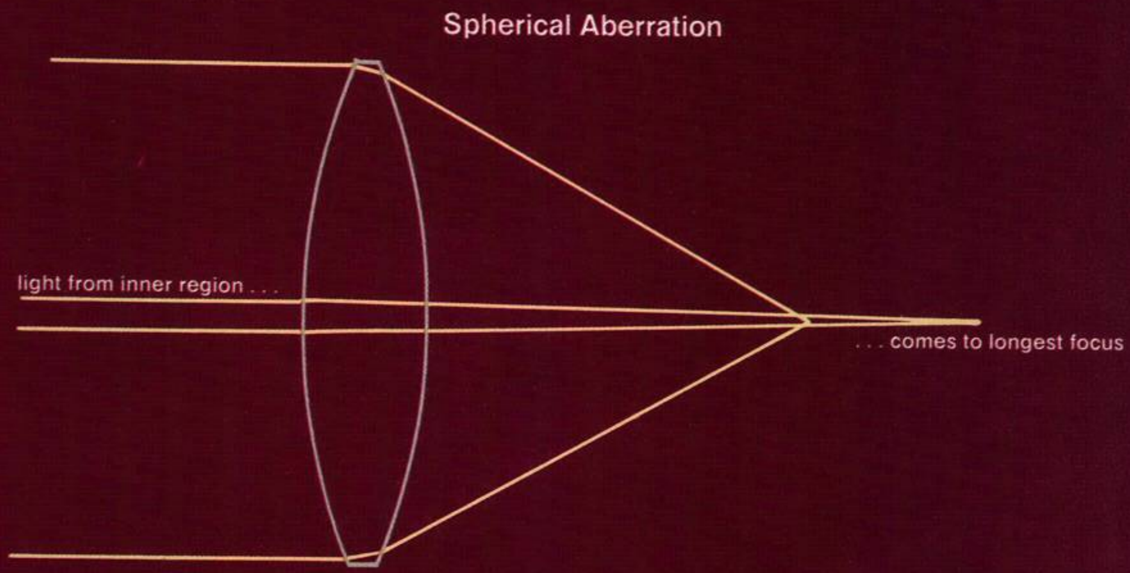
Your first question is bound to be, "What is a dioptric telescope?". This is the most common form of telescope; in fact, you probably own one if you have a pair of binoculars, a spyglass or small refractor! A check of the dictionary reveals that a dioptric telescope is one that forms its image by means of lenses. The common name in astronomical use is *refractor* (a typical small refracting telescope is shown in the cutaway of pages 52 and 53).

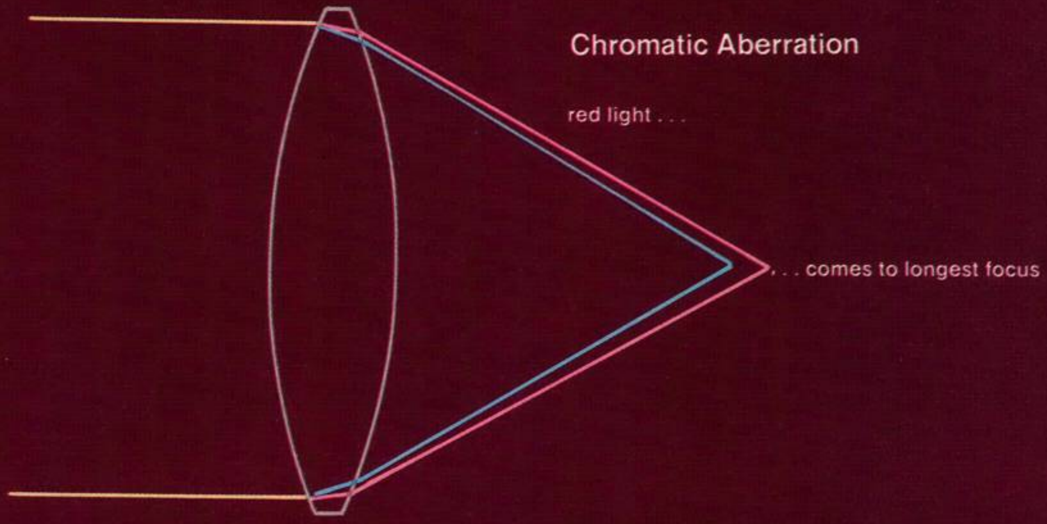
The most important part of a refractor is the objective, which collects light from an object and causes it to converge to an image. The image forms in the focal plane, at a distance usually about 15 times the diameter of the objective away from it. You'll notice that two pieces of glass are used in the lens, so your next question would probably be: "Why not just one? It might save cost and simplify the construction."

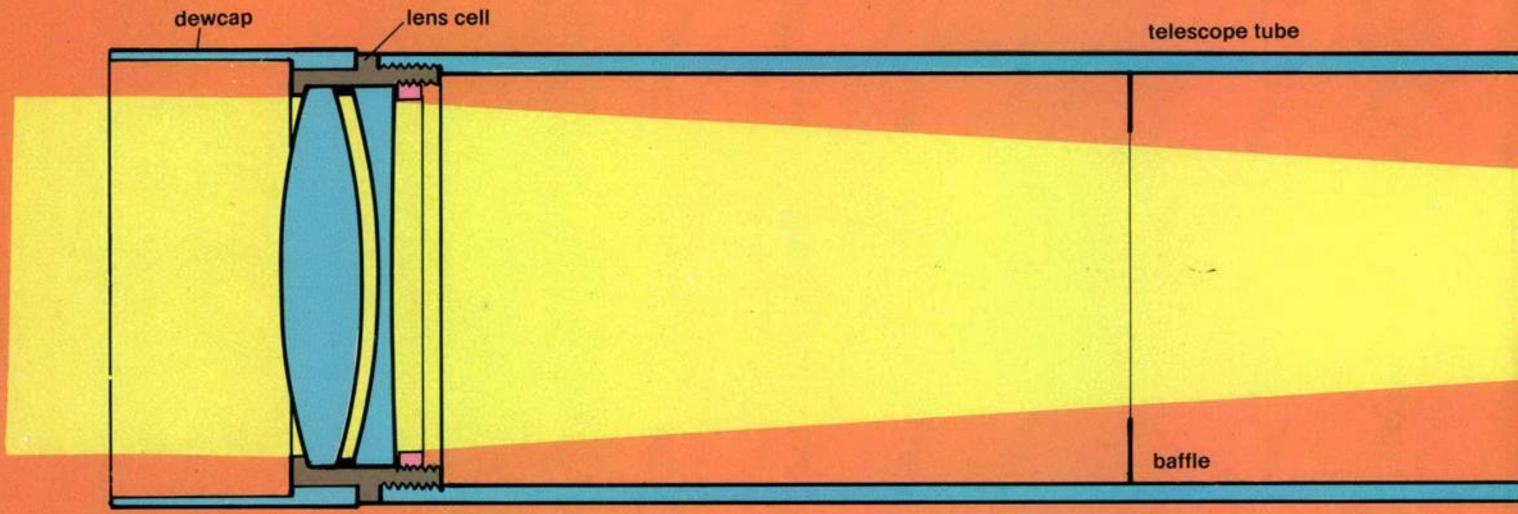
For about 120 years — from 1608 when Dutch spectacle maker Hans Lippershey demonstrated his telescope, until 1729, when Chester Moor Hall, an Englishman, demonstrated the two element telescope objective — single glass elements *were* used in telescope. But the two element objective is needed because serious *aberrations*, or errors, limit the practical use of telescopes with a single lens.

There are actually two types of errors that make single lenses undesirable. The lower part of the drawing on page 51 shows light rays focusing at different distances from the lens depending on their


Passive Element
Active Element
plane surface
curved surface
rays diverge or converge
rays continue parallel


Spherical Aberration
light from inner region . . .
. . . comes to longest focus


Chromatic Aberration
red light . . .
. . . comes to longest focus



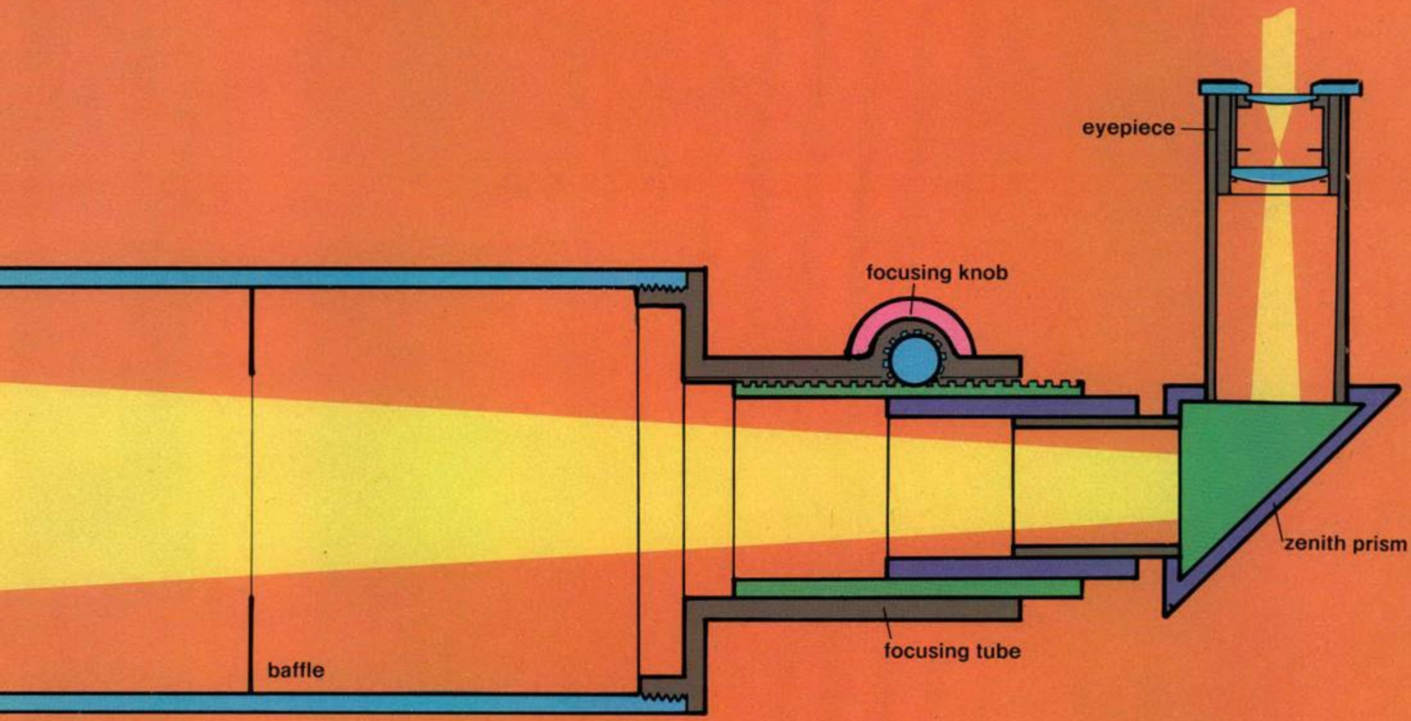
height from the center of the lens. This error is known as *spherical aberration*. The lower portion shows that light rays of white light emerge from the lens broken into a spectrum, or rainbow of light — with the red light focusing farther from the lens than the blue. This error is known as *chromatic aberration*. Both aberrations make the image blurry and fuzzy.

Early astronomers found they could not eliminate these two errors, but by careful design they could minimize them. The solution was to make the focal length (the distance from the lens to the image plane) extremely long. The result was, of course, that handling and using the telescope became a real problem. A modern five inch refractor with a focal length 15 times the lens diameter is six feet long — awkward enough to handle, but imagine trying to use it if the lens were single and its focal length was 408 inches (33 feet)! Indeed, Christian Huygens, the famous observer and telescope maker, made an eight inch single lens telescope 2,040 inches long (170 feet)! The patience and ability of those early astronomers to point and view through such instruments is truly inspiring.

The Achromatic Objective

The *two element objective* was invented when two types of glass elements were combined to correct the spherical and chromatic errors of a single piece of glass. The front element often has two convex surfaces and is made of *crown glass*. The second element is made of *flint glass* and has a steep concave surface with the second surface either flat or slightly concave or convex. Flint is a much denser kind of glass, and a lens made from it has, by design, aberrations equal and opposite to the aberrations of the crown element. However, light passing through the two glasses is still bent (the technical term is refracted), so the combination lens forms an image at a proper focal plane. It isn't possible to fully correct a two element lens using common types of glass, but the usual residual aberrations are so small as to not be objectionable in use. A small amount of color does remain and may be noticeable on bright objects; if you see it, it's called *secondary spectrum*. By using very unusual and expensive glasses, it *is* possible to make an objective with virtually no secondary spectrum, or by using a combination of three glasses, you can achieve this colorless result. Such lens combinations (called *apochromatic lenses*) are expensive — well beyond the pocketbook of most astronomy enthusiasts.

In our example the objective has the two pieces of glass separated from one another, but on binoculars and small refractors the two elements are cemented together with transparent glue. Why not cement telescope lenses also? First, the two glass types have different amounts of expansion when exposed to heat and could become distorted as the temperature changes. Second, separating the glasses gives a lens designer more design variables with which to work, permitting a better finished product. To further improve performance, most lens surfaces are coated with a magnesium fluoride antireflection coating that increases transmission of



light through the glass by reducing reflection off the surfaces.

The Zenith Prism

Following the converging light from the objective toward the focal plane, you'll next find a passive element — a right angle prism — that changes the light path so it is now going at right angles to its original direction. The purpose of this prism (which is used most of the time with a refractor) is to provide a convenient location for the observer's eye. Except when you view close to the horizon — not usually a very practical situation anyway, because of atmospheric turbulence — the focal plane of a refractor tends to be located low and in an awkward position. If you try to look up the optical axis toward the object under examination, your neck will start to hurt! The first thing you'll learn about astronomical observing is that unless you are comfortable and relaxed, it isn't possible to either enjoy the view or to adequately concentrate on looking carefully. Since this prism is left on a refractor 95 percent of the time when you point the telescope at objects low in the sky, instead of removing the prism, just rotate it to bring the light out parallel to the ground and sideways.

Theoretically a prism acts like a thick parallel plate of glass in a converging beam of light. The result is some chromatic aberration. Fortunately, on the thin cone of light in most refractors, the error is so small that it can be ignored. But if a very short refractor is used, a zenith prism — in which the focal length, instead of being 15 times the lens diameter, is made about five or six times the lens diameter — can introduce noticeable color in the final image.

Barlow Lenses

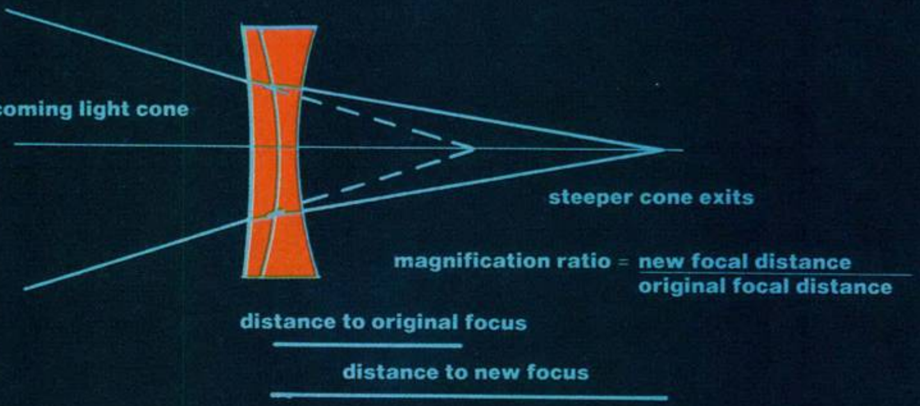
Another active element, called a Barlow lens, is usually supplied with most small refracting telescopes. A Barlow is usually a lens of one or two pieces of glass with concave outside surfaces (see the drawing on page 54). Single element Barlows can introduce both spherical and chromatic aberrations, so it's standard to use two pieces of glass (a crown and a flint, as in the objective) to obtain good color and spherical corrections.

A Barlow is an amplifying element. If it's placed inside the original focus of a telescope, it will extend the focus to a new location and at the same time increase the instrument's focal length by 1-1/2 to 2 times! The amount of amplifying action is determined by dividing the distance the lens is placed inside the original focal plane by the length of the newly extended light cone. For example, if the intercept distance is one inch and the new light cone has a length of 1.5 inches, then the focal length of the telescope will be increased by 1.5 times. Your 45 inch focus lens would have a new focal length of 67.5 inches! If it's well made and not forced beyond its limits, a Barlow lens becomes an important tool for the observer — allowing you to increase the focal length of your objective to obtain higher power, if and when observing conditions allow it.

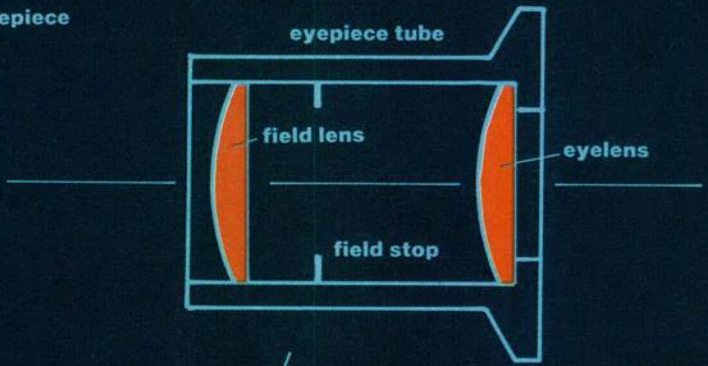
The Eyepiece

The final active element of a refracting tele-

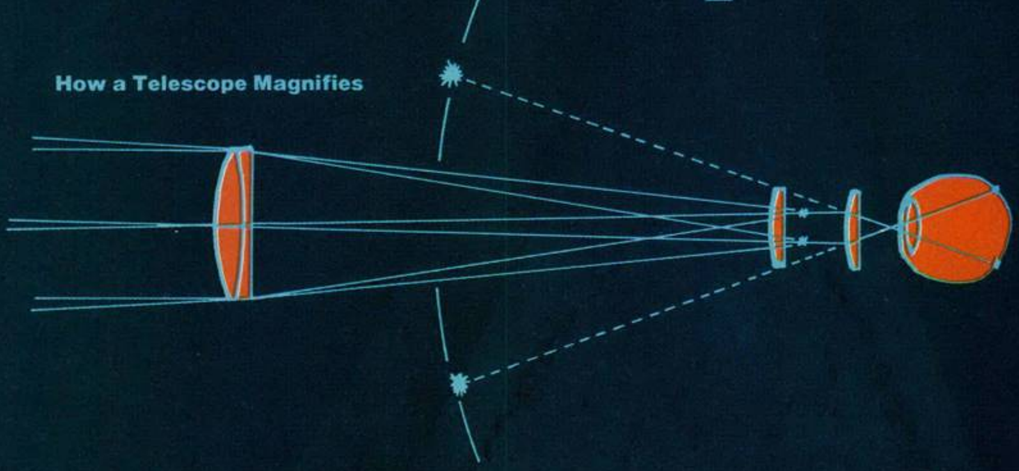
Barlow Lens


incoming light cone
steeper cone exits
magnification ratio = new focal distance / original focal distance
distance to original focus
distance to new focus

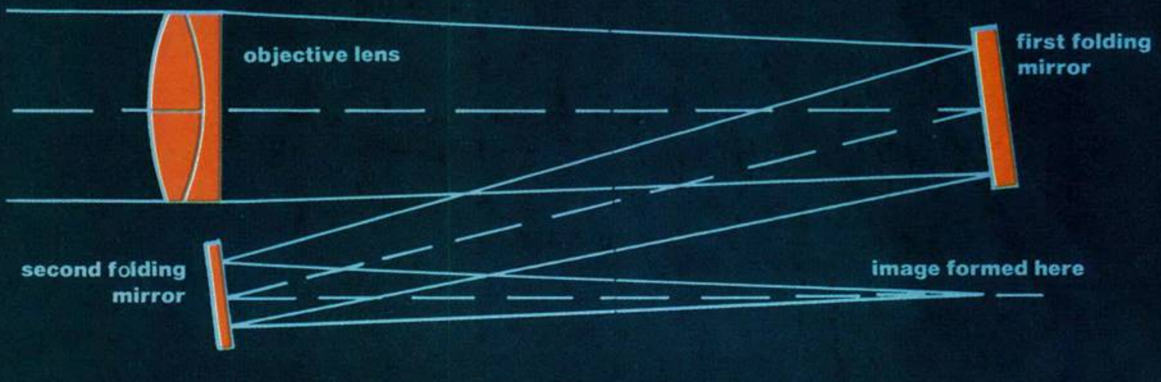
Huygens Eyepiece


eyepiece tube
field lens
eyelens
field stop

How a Telescope Magnifies



Refractor With "Folded" Light Paths


objective lens
first folding mirror
second folding mirror
image formed here

scope is the eyepiece (sometimes called an *ocular*); it is with this accessory that the actual magnification of the image takes place. For the same reasons that you can't use a single lens for the objective, you can't use a single lens for the eyepiece — so eyepieces are always made with two or more lenses. In fact, some special purpose oculars have as many as six pieces of glass in them!

A low cost refractor is usually supplied with one of the simplest and oldest kinds of eyepiece: a two element design called a *Huygens* eyepiece. This ocular consists of two simple glass elements, both having convex-plano construction, mounted with the convex surfaces toward the light coming from the objective. There is a *stop* (controlled opening) between the lenses to define the focal position of the assembly and to provide a pleasing sharp edge to the field of view. This type is called a *negative* eyepiece because the focus lies between the lens elements. (You can't use it as a magnifier for looking at stamps!) Huygens oculars are designed for dioptric long focus telescopes (small refractors, that is). In spite of their simplicity, they generally give very satisfactory images.

Using a Telescope

To keep the optical elements aligned (so they won't present a distorted image), they are assembled in a tube. The objective is at the front end, and the zenith prism, or Barlow, and eyepiece are at the other end. To keep stray light from bright objects just outside the field of view from reflecting off the walls of the tube and interfering with the main image, manufacturers and telescope makers put several light baffles inside the tube to intercept stray light and prevent it from reaching the back end of the tube.

In an astronomical telescope, *parallel* light from a celestial object enters the objective and finally leaves the eyepiece also in a *parallel* light bundle. In optics, this is known as an *afocal* system. But if the light comes in parallel and goes out parallel, how does a telescope magnify? The secret is all in the angles: If two beams of parallel light from two close stars enter your telescope, they will exit at a much larger angle, so when you look, you'll see them farther apart! The number of times the original angle increases is the magnification. Luckily you don't need to measure any angles to find the power, however. If you divide the focal length of the objective lens (usually given on the telescope tube) by the focal length of the eyepiece, the result is the magnification or power. For example, with a focal length of 45 inches, a one inch ocular will give 45 power (45x), while for high power a 1/4 inch ocular will give 45 ÷ 1/4 = 180x. This applies to any visual telescope, regardless of its construction, unless you use an accessory such as a Barlow lens that changes the focal length. If that's the case, use the new extended focal length in determining its power. A word of warning: If the objective focal length is in inches, use eyepiece focus in inches; if one is in millimeters, use the other in millimeters. Don't mix units and your result will be correct.

Robert E. Cox is one of the best known telescope makers in the United States. His articles, talks and enthusiasm for telescope building have been responsible for introducing thousands of people — who might never have dreamed of owning a fine telescope — to astronomy. Cox wants to help you too: If you have questions about building a telescope, please write to him c/o ASTRONOMY. Your questions will help ASTRONOMY plan future Equipment Atlas articles, and you may find yourself answered in In Focus.

Cox, employed at McDonnell Douglas as a senior engineer doing optical fabrication, testing and evaluation, formerly wrote for **Sky and Telescope.**

Refractors are long, and can be awkward to mount and handle. It's possible to shorten a refractor by folding the optical path with flat mirrors (see the diagram on page **54**). For many years the French have used a 23-1/2 inch refractor at the Pic-du-Midi Observatory in the Pyrenees (over 9,000 feet above sea level!) as a folded telescope with excellent results. Unitron now has a three inch refractor that has its four foot length compacted into a tube only 19 inches long. The problem you would have in making such an instrument is in the high quality needed for the two folding mirrors: They need to be flat to within one or two millionths inch!

If you're buying a small refractor, remember a few words of caution on how they are sometimes advertised. Any telescope will transmit light at any power or magnification, but the vital question is, "Are the results of any practical value?" With a low cost refractor the image will not be bright enough or sharp if the power exceeds 50 magnifications per inch of the main lens or objective — meaning about 180x *maximum* with a three inch instrument. Unfortunately, like advertisements on the horsepower of cars, the manufacturer may try to impress prospective buyers with a large figure for the telescope's power. If the ad claims 300 or 600 power, don't believe it! At such powers the image would be too faint to be of any value, and with the simple oculars that are supplied on a low cost item, the optics just aren't capable of delivering a good image at such limits. If, however, you ignore the exaggerated claims and use the scope at lower practical powers, you'll probably have a very enjoyable time with your instrument.

So that's what you'll find in your telescope — if it's a refractor. Robert Cox will discuss other types of telescopes — Newtonians, Cassegrains, Maksutovs, Schmidt-Cassegrains — and all the rest in future Equipment Atlas articles.

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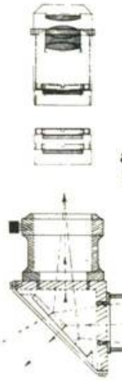

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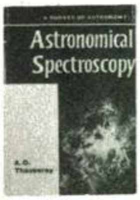

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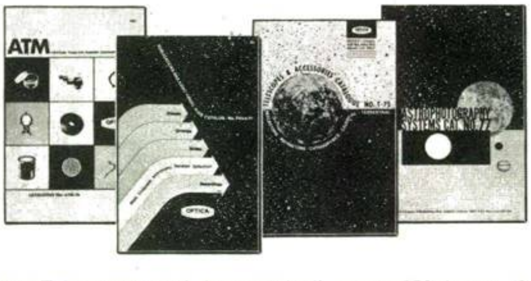

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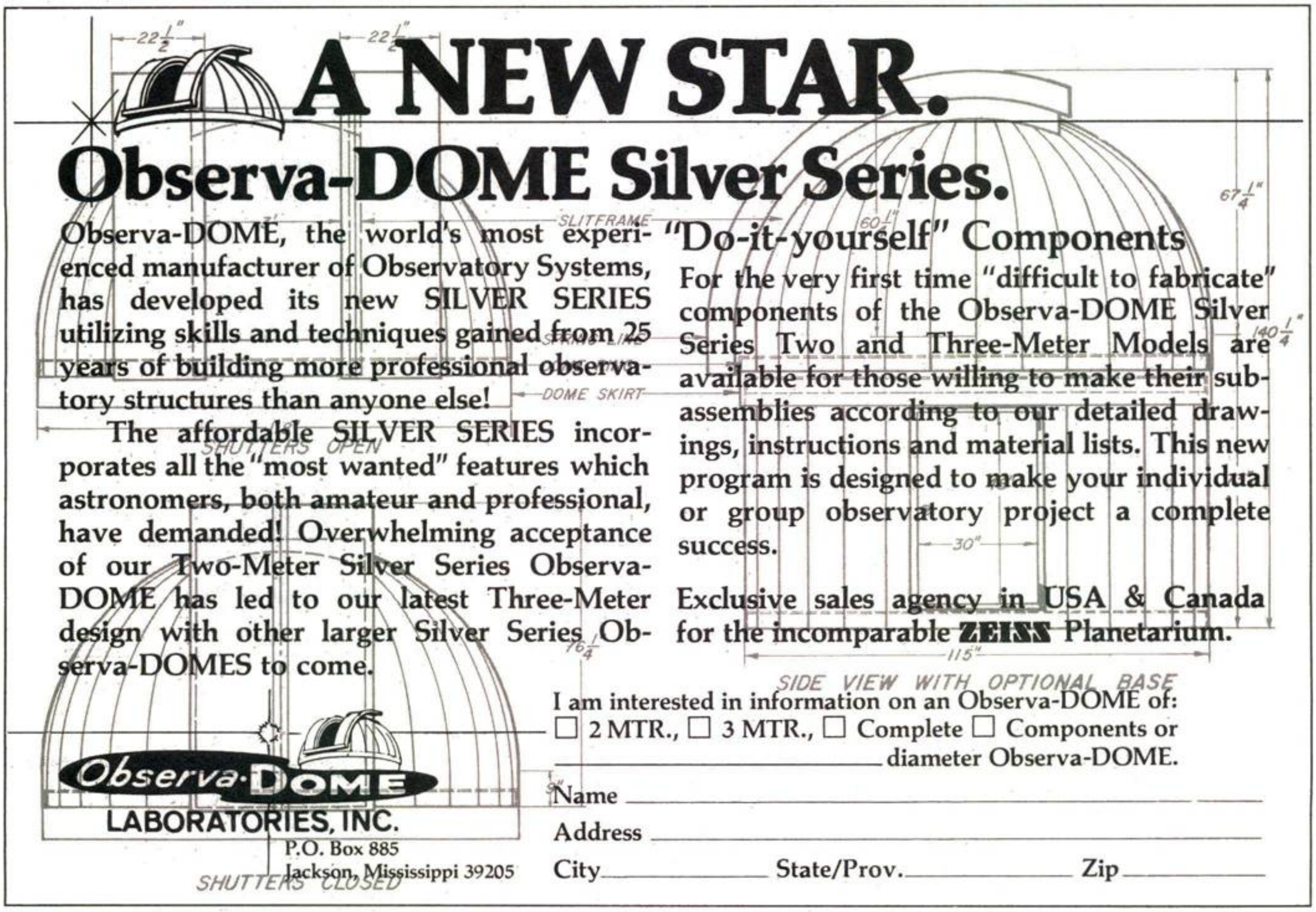

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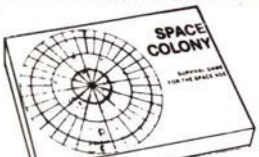

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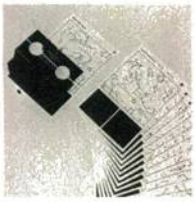

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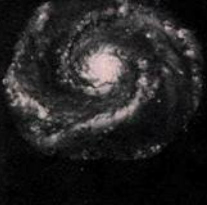

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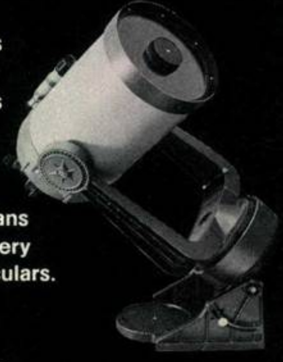

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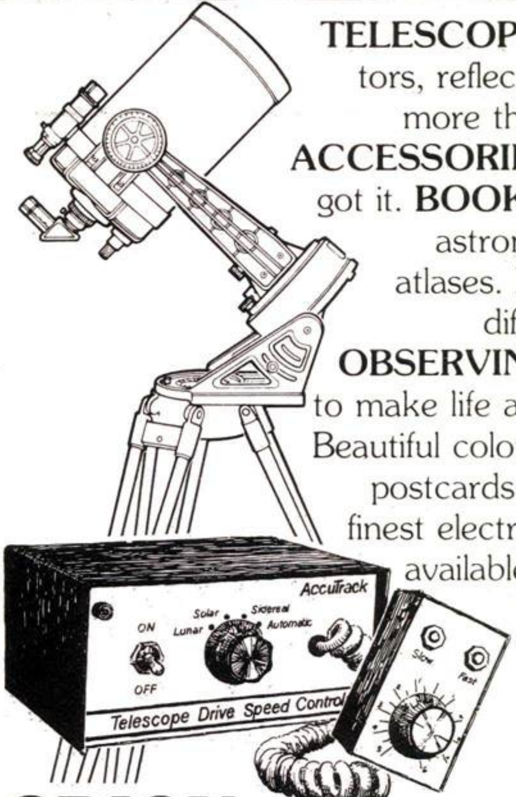

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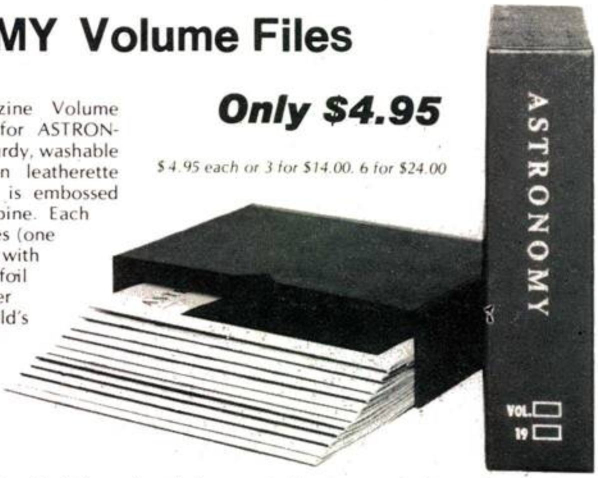

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ASTRO-NEWS

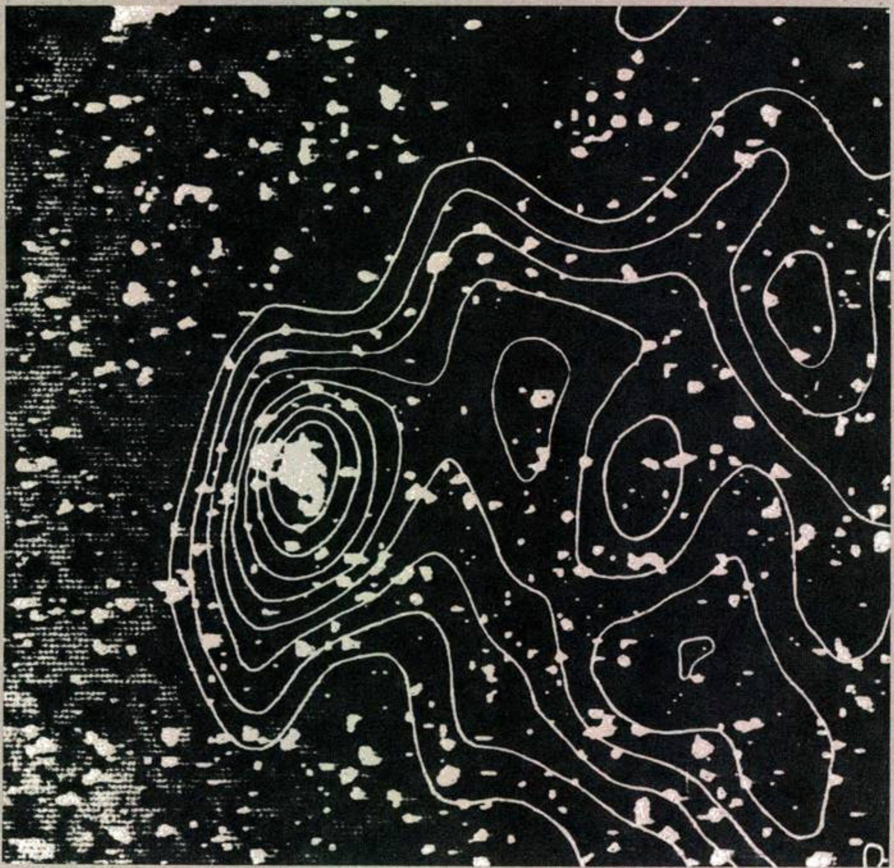
Latest News From the World of Astronomy

Optical Emission Found In 3 Radio Galaxies

In a new observation that pushed photographic astronomy almost to its limit, astronomers have detected a dim glow of light from the giant radio clouds of three galaxies.

William Saslaw, Anthony Tyson and Philippe Crane used the 158 inch Kitt Peak reflector in a photographic survey of the radio components of certain galaxies. They selected a trio located well away from the plane of our own Milky Way galaxy. This procedure lowered the chance that a faint local star would confuse the issue by accidentally coinciding with a remote radio source.

In excellent viewing conditions, Saslaw and his colleagues obtained photographs of the radio emitting zones of galaxies 3C-285, 3C-390.3, and 3C-265 [listings from the **Cambridge ("C") Catalog of Galaxies**].



This photograph shows the optical emission (23rd magnitude) from the radio galaxy 3C-285, as surrounded by contour lines that mark areas of radio emission. The original plate was made using the Kitt Peak 158 inch reflector, and was then analyzed at Kitt Peak and Berkeley using image processing devices. To further insure accuracy, the photograph was matched precisely with the latest high resolution radio maps of the area. Photograph by William Saslaw.

They pressed exposures to the limit in an effort to capture precious traces of light from the radio clouds.

Image processing devices at Berkeley and Kitt Peak enabled them to make a careful analysis of the smudges of light on the plates, and to accurately assess the celestial positions of the nonstellar images.

To aid interpretation of the optical pictures, the National Radio Astronomy Observatory (in West Virginia) and England's Mullard Radio Astronomy Observatory contributed the latest high resolution radio maps of the galaxies. This information, which complements the optical data, enabled the researchers to achieve a precise match of the optical and radio images.

Saslaw explained his findings for galaxy 3C-285 to ASTRONOMY: "We've found optical emission within an arc second [an extremely precise measurement] of the peak radio intensity in this object. Our calculations show that the probability of seeing a 23rd magnitude object right there by pure chance is less than one percent. You can see a blurred object on our photograph, enclosed by the contour lines that radio astronomers use to mark out regions of radio emission."

When asked if it might be an unfortunate coincidence, Saslaw replied, "I doubt it; we've also detected light from the radio lobes of 3C-265 and 3C-390.3. So it's rather unlikely that we have not genuinely detected optical emission from these radio clouds. And there are signs that at least one other galaxy is glowing faintly."

Although the clouds are optically faint, Saslaw said that for 3C-285, the optical luminosity (10^{31} kilowatts), is 10 times larger than the radio luminosity of that region. "A significant amount of the cloud's energy emerges as light."

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Center for UFO Studies Profiled

On June 24, 1947, Kenneth Arnold, a businessman piloting a private aircraft, reported observing nine disks flying from north to south near Mt. Rainier (Wash.). It was the first such observation to capture the attention of the press and public, and thereby made history.

Public interest in unidentified flying objects continues to grow, especially among students of all ages. Astronomers are continually beset with questions about UFOs, and how to answer them is definitely a dilemma. Most persons who ask these questions assume that UFOs are synonymous with visitors from outer space. This confuses a *theory* of the phenomenon with the *phenomenon itself*, which exists quite apart from whatever may be thought about it.

Part of the dilemma is that astronomers, of all people, are aware that very likely "we are not alone" in this vast universe — but they are also aware, far more than most other people, of the truly vast distances between the stars. They often hear the question, "Well, we've gone to the moon, so why can't someone come here?" They must patiently answer that this is not quite the same thing — the nearest possible planetary system is more than 100 million times farther away than our moon!

It was for reasons such as these that the Center for UFO Studies was established.

According to Dr. J. Allen Hynek, center director and professor of astronomy at Northwestern University, the organization has four principal objectives:

1) To pursue rigorous study and analysis of the UFO phenomenon, calling upon the talents and services of the center associates and employing existing facilities (computers, physical and biological laboratories, etc.) at universities and in industry wherever possible. The center is a focus for persons to use the facilities for research. To do this, however, certain conditions must be met; research proposals must be approved by the center's scientific board and the results published. While the ultimate objective of the center is solution of the UFO enigma (should this not lie within our present scientific limits), it is currently documenting and organizing data on the phenomenon as thoroughly as possible.

2) To operate UFO Central, a clearing house to which persons can report UFO experiences without fear of ridicule or unwanted publicity, and with the knowledge that such reports will be given serious attention.

3) To provide bulletins and technical reports, and be a source of reliable information about the UFO phenomenon to schools and universities, scientific organizations and the public in general. The center publishes a quarterly bulletin, which contains research and discussions on various aspects of UFOs.

4) To assist and help guide correlative studies conducted in the United States and elsewhere through international symposia and conferences. (It is not generally known, for instance, that active work in the field is being pursued on several continents.)

To aid in research, the center maintains a computer bank (named UFOCAT) of sighting reports from all sources, located in Princeton, N.J. This file contains some 79,500 reports of UFOs which, after allowance for duplication of sighting sources, leaves over 55,000 primary entries. UFOCAT, which was initiated by Dr. David Saunders in 1967, represents a major research tool for center scientists. It provides a standard format for reports of varied content, and makes them available in a random-access manner. The data is available "at cost" to those whose interests are scientific, and who will make their findings available to others.

Other "tools" of the center are its network of voluntary field investigators, its library (including the microfilms of the Air Force Project Blue Book), and scientists at various universities and laboratories who use the center as a focus for their interest and work in this subject.

"I am not saying that the level of public interest is what justifies continued research; rather, the number and nature of the sighting reports seem to indicate that we are dealing with more than a passing psychological aberration," Hynek said. "UFO reports just will not 'dry up and blow away'. The phenomenon persists, and the continued flow of reports from all over the world poses a real dilemma to men of science. On the surface, the whole subject seems silly; the reports do not constitute 'hard data', and physical evidence is sparse. Yet, there are too many credible witnesses and too many similarities and confirmations in the reports."

The UFO reports of greatest interest to the center, and of the greatest scientific potential, are those termed *close encounters. Close encounters of the first kind* are sightings reported to have occurred within a few hundred feet of the witnesses, when the chance of a misidentification of Venus or a balloon is minimal.

According to Hynek, *close encounters of the second kind* are of most direct scientific interest since they involve physical traces left by the UFO: burned areas on the ground, charred vegetation, effects on electrical equipment and physical effects on people and animals. These offer a way, so to speak, of bringing the UFO into the laboratory despite the absence to date of any authenticated

Center *continued on page 67*

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"part" of a UFO. A catalog of over 1,000 such cases is available through the center.

By far the most interesting and intriguing of all, however, are the *close encounters of the third kind*, Hynek said. Here encounters with "intelligence" other than our own are reported. "Entities" or "UFOnauts" are indeed reported, and from all over the world. Over 1,000 such reports have been cataloged by investigators and are available through the center.

To date there has been no hard evidence to either prove or disprove the validity of such reports, but the reports do exist, and the fact that they exist is worthy of study, Hynek said. The following demonstrates the center's investigation of a "typical" report:

At approximately 1:20 a.m. on Oct. 22, 1976, a single witness observed two triangular shaped "vehicular" objects hovering over a swampy area in Woodbury Township, Minn. After a few minutes, the two objects, which had yellow and red lights, started to move and came over the witness' car before disappearing in the distance.

After questioning the witness, a center investigator went to the site of the observation. He found a small clearing where the vegetation was quite different from the rest of the swamp. In a rectangular area measuring approximately 50x20 feet, the soil was exposed and appeared to have been pulverized and turned over, and there were places exhibiting round holes about the size of a quarter, several inches in depth. Soil samples were taken, and these and control samples were subjected to thermoluminescence tests. The tests revealed that some of the disturbed soil had been exposed to heat, while other samples indicated having been irradiated by some kind of high energy radiation.

Shortly after Arnold's sighting, the Air Force started a series of investigations, beginning with Project Sign in 1948. The following year Project Grudge began, continuing until 1952 when Project Blue Book started (and continued until 1969). The Rand Corporation (a private concern) was also contacted by the Air Force to make an independent study of UFOs.

In 1967, the Air Force commissioned Dr. Edward Condon of the University of Colorado to head a committee to make an independent audit of the material gained up to that point. According to Hynek, his report was negative, and as a consequence the scientific world felt the books were closed on UFOs. However, Hynek and many other scientists were unable to accept that report: The Condon Committee studied only 90 cases and could not explain 1/3 of them; of the remaining, many were obviously identifiable and should not have been included in the study in the first place.

Hynek feels Condon's summary did not bear a direct relation to the findings of the staff and represented more Condon's beliefs than the results of case studies. The committee studied the wrong problem: Instead of examining the evidence to see whether the UFO phenomenon was worthy of scientific study, they asked the question, "Are UFOs from outer space?" Thus they studied a theory and not the phenomenon.

Today, according to Hynek, the Condon Report is regarded as inadequate and misleading. There is a growing feeling, even among members of the original committee, that the UFO question should be reopened and properly studied. In a recent poll conducted by Stanford University Prof. Peter Sturrock of the members of the American Astronomical Society, over 53 percent of those astronomers responding believed that UFOs were too significant to ignore and that they were worthy of serious scientific study. (Fifty-two percent of the 2,611 members responded to the questionnaire.) This thinking is increasingly echoed in other quarters.

Hynek said it was for this reason — in anticipation of such a need — that the Center for UFO Studies was created in 1973. With all these developments in mind, the center is redoubling efforts to fund and organize further research without official governmental support. Their newsletter, the **International UFO Reporter**, has become a significant link with people around the world, educating them as to what constitutes a valid sighting and what does not. Through it, they can keep those interested in the subject conversant with the latest trends and developments in the UFO field. Use of the newsletter is proving, in some areas, to be a valuable adjunct to the study of science in junior and senior high schools since its approach illustrates the scientific method in action; it teaches scientific self-discipline in the gathering of facts.

For those interested in contacting the center, write to: The Center for UFO Studies, 964 Chicago Ave., Evanston, IL 60202.

Physicists Design Experiment to Study Static Electricity Problem on Satellites

Physicists at two NASA centers are participating in a project that may lead to an understanding of a problem which for years has plagued the makers and users of communications satellites.

Communications satellites are usually placed in a geosynchronous, or stationary, orbit so that they keep pace with Earth's rotation and remain over the same land area.

This orbit is about 22,000 miles (35,400 kilometers) above Earth, where local conditions are greatly influenced by the ionosphere below and the magnetosphere above.

Plasma gases (hydrogen, helium and oxygen) escaping from the magnetosphere bombard satellites in stationary orbit with electrically charged particles, sometimes causing a static electricity buildup of dangerous proportions. The static electricity can then cause arcing (electrical sparks) on the satellite's surface that in turn can damage solar power cells and thermal insulation, and generate interference with transmission of signals, resulting in garbled information and spurious switching of spacecraft functions.

In an attempt to obtain scientific data on the phenomena, NASA's Marshall Space Flight Center and Goddard Space Flight Center are joining the Air Force in a project called Satellite Charging at High Altitudes (SCATHA).

The Air Force will launch a satellite in January 1979 carrying an array of scientific and engineering instruments to study satellite electrostatic charging at and near geostationary orbit.

Marshall's part of the payload, an instrument called a Light Ion Mass Spectrometer (LIMS), will measure density, temperature and speed of low energy ions. Sensors will separate the ions of hydrogen, helium and oxygen, and record the speed and number of each type.

Goddard is providing two major experiments. One deals with measurements of space electric fields by long antenna probes, and how the presence of the spacecraft disturbs the electric fields surrounding it. The other is related to the measurement of space magnetic fields with a three axis flux gate magnetometer.

Charged ions move at speeds from zero to almost the speed of light, and their speed is determined by the energy they contain. The LIMS will detect and count those ions moving in the low energy range up to about 100 electron volts. The other instruments will detect those in higher energy ranges.

It's anticipated that the data gathered will yield a basis for understanding problems of static electricity charge buildup, and for developing a method for immunizing satellites to this phenomenon.

Galaxy Clusters Examined

A recent discussion meeting of the Royal Astronomical Society centered on the origin and properties of galaxy clusters — the largest aggregates of matter found in the universe.

[Galaxy clusters fascinate cosmologists. Rich clusters are families of hundreds of galaxies bound by gravity into a cloud a few million light-years in size. With a six inch telescope you can see the brightest of the 2,500 galaxies in the great Virgo cluster. This immense grouping includes M-87, the galaxy of greatest known mass. Clusters of galaxies are important indicators of the large scale structure of our universe; understanding how they evolved is a major task of theoretical astronomy.]

Sverre Aarseth, of the Cambridge Institute of Astronomy, showed a computer produced movie that gave an account of one possible way clusters are created. The computer program was used to follow the behavior of 4,000 model galaxies which were initially scattered at random in a small part of the universe. Gravity gradually corraled most of the galaxies into clusters. According to George Efstathiou of Durham University, tidal forces within the clusters can set the galaxies spinning.

Galaxy clusters are the richest areas of matter in the universe. This rich cluster located in the constellation Peacock includes examples of a barred spiral galaxy, elliptical galaxies, and edge-on spiral galaxies. Photograph courtesy of the UK Schmidt Telescope Unit of the Royal Observatory, Edinburgh.

Apart from galaxies, clusters also contain gas. Because the mass is unknown, there is controversy about the properties of this gas. Researcher Paul Nulsen pointed out that x-ray data tend to show that the gas contains a good deal of iron. But this metal can only be made by nuclear processes in stars, so how did it get into the voids between the galaxies? Scientists don't know the answer yet.

Oxford scientist James Binney gave a tour of the life cycle of a cluster. He explained that tidal interactions within a cluster caused the heaviest galaxies to fall to the center of the cluster.

Binney showed how a galaxy can change as it moves through intergalactic gas. Ordinary spirals get turned into the spheroidal (S0) galaxies because they are traveling through the intergalactic medium at 500 miles (650km) per second. This is a supersonic speed, and consequently all the galaxy's gas gets blown out by a terrific gale. The end result is a gasless S0 galaxy.

An amusing aspect of the overall evolution of a cluster is that it seems to follow classic capitalist principles. Galaxies with the highest mass (the largest "natural resource") grow even bigger at the expense of the rest of the community. Their gravity helps them gobble up small galaxies and the cluster gas. This may be why many clusters are dominated by a single giant galaxy — star piles at their centers!

Using photographs of very distant clusters (taken in Australia with the UK Schmidt telescope), Durham astronomer Richard Ellis has looked at thousands of faint galaxies. He has found that far-off objects tend to cluster less than local galaxies. Remembering that remote clusters are observed at an earlier time, this indicates that clusters grow in membership as the universe ages, exactly as Aarseth's models require. However, cosmologist G.C. McVittie cautioned that Ellis might just have had bad luck and worked by chance at an unusual part of the sky where clusters are sparsely populated. Ellis was urged to look at a few hundred thousand galaxies — a lifetime's work!

Optical

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The simplest explanation of the glow in the radio clouds is that it is high energy synchrotron radiation. Electrons traveling at nearly the speed of light (99.9999 percent) go screeching through the magnetic field, causing a force to act on the reckless electrons. As a result they move on a curved path and, in accordance with fundamental laws of electromagnetism, emit energy called synchrotron radiation. (The term was derived from the effect first being seen in the atom smashing machines of the same name.)

The Crab nebula, remains of a supernova observed in July 1054, is a source of radio and optical synchrotron radiation. The giant galaxy M-87 in the Virgo cluster has its well-known jet of synchrotron light. Now it seems radio galaxies in general may be emitters of the electric-blue synchrotron light.

For theories, the discovery has the following significance: Electrons that emit the light cannot live for more than 2,000 years; they're just too exhausted to continue sending signals after that. So, how does the radio galaxy make the new electrons that are needed to keep the show going? There must be a mysterious "engine" making new electrons inside the radio clouds.

Further deep sky photography is needed to consolidate this work, which indicates that optical emission in radio lobes may be a common feature of radio galaxies. Additional spectroscopy and photometry, as well as polarization measurements, can confirm the synchrotron hypothesis. And finally, observations at high resolution in all wavebands should help the theorists construct detailed models of the radio and optical clouds.

Astronomers Propose Search for Extraterrestrial Intelligence

An unprecedented five year, $20 million search for extraterrestrial intelligence has been proposed by astronomers at NASA's Ames Research Center in Mt. View, Calif. and the Jet Propulsion Laboratory in Pasadena.

The project, named SETI, would match existing radio telescopes with data processing equipment to search for artificial radio signals, according to Dr. John Billingham, chief of the SETI Project Team at Ames.

If funding is approved by Congress, a full time search could begin by 1980. The first step would be to build multichannel spectral analyzers (MCSAs) that would allow astronomers to monitor one million channels simultaneously in the "microwave window" of the electromagnetic spectrum, said Billingham.

Astronomers believe that electromagnetic radiation is the most economical and efficient means for civilizations to communicate across the galaxy. Microwaves of roughly 3mm to 30cm wavelength travel through a natural window in the spectrum that is particularly free of interference — so it seems logical to listen there first.

Beginning with Project Ozma in 1960, previous searches have been sporadic and short lived. Several current programs initiated in the early 1970s can listen to only a handful of frequencies at one time. The MCSAs, already designed and tested by computer simulation, will give SETI at least 1,000 times the high resolution frequency coverage now available.

SETI will be an effort of two research teams with radically different search strategies, according to Billingham. Astronomers at JPL (at which Robert Edelson is the project manager) will listen for narrow band 300Hz (cycles per second) signals in 1/4 the microwave window using the 85 foot (26m) Goldstone radio telescope in the Mojave Desert. A second SETI team at Ames will use three large radio telescopes, including the giant 1,000 foot (305m) dish at Arecibo, with the two others yet to be chosen. The telescope will be used to examine the so-called "water hole" with higher resolutions of 1 to 5Hz.

The water hole is a tiny slice of the microwave window between the spectral lines of the two building blocks of water — hydrogen at 1,420 million Hz and the hydroxyl radical (OH) at 1,662 million Hz. SETI astronomers speculate that water based life on other planets may send signals through this part of the spectrum.

Discovery of an artificial signal "would rank with the most important discoveries of our civilization," Billingham said. "It would tell us there's at least one other civilization out there."

Neither Billingham nor Edelson are certain of SETI's chance for success. But they will carefully check any signals they receive. "We want to be sure that the first announcement of the detection of an extraterrestrial signal is made only once," Edelson emphasized.

No one knows what another civilization might be like. "The one thing we can say is that they'll be much older," said Billingham. "We're just 10 years old when it comes to our ability to talk across the galaxy." Chances are we'll hear from a technological society thousands, perhaps millions of years older than Earth's.

Undoubtedly, they'll have much to say. Even if the message is carefully packaged for easy decoding, Billingham suspects it will not be easy to understand an alien culture. "The effect might be a little like discovering a new continent on Earth with a people and history of its own," he suggested. "I don't think there would be any immediate, sudden impact. To fully explore the message might take decades. Its content would gradually seep into the intellect of our civilization."

To date, however, the only life we know of inhabits a planet that orbits a G2 dwarf star called the sun, Billingham said. So the Ames half of the SETI effort will focus on sunlike stars within a few hundred light-years of Earth. "We'll search F, G and K stars one at a time, beginning with the closest ones and slowly going farther out as the sensitivity of listening devices improves," Billingham explained.

Ames astronomers will tune into each star for 10 to 30 minutes on a million different channels. "The total observing program will probably run into hundreds of stars," Billingham said. "It might go up to one or two thousand if we get lots of observing time." (The Ames team will have to negotiate for time on the radio telescope.)

JPL astronomers, on the other hand, will search most of the sky for artificial signals. "We'll be looking at 80 percent of the stars in the universe over a wider frequency range (and with much less sensitivity) than the Ames program," said Edelson. In fact, any signals JPL might detect must be a million times stronger than those the Ames group could pick up. SETI astronomers think such an all-sky survey is necessary, however, just in case an extraterrestrial civilization is signaling with an enormously powerful transmitter.

JPL has requested $14 million for a seven year SETI program, including five years of actual observations. The Ames team is asking $6 million for its five year search. "That's a very small budget, but it gets us on the telescopes and may get us a signal," said Billingham.

President Carter is expected to include $20 million for SETI in the 1979 federal budget. Final Congressional approval of SETI could come as early as June 1978. "We're very optimistic that approval will be granted," Edelson said. "All the signs look good." Barring financial hangups, SETI field tests will begin in late 1979, and the full time search in 1980.

Besides listening for messages from other worlds, SETI may yield valuable data for radio astronomy. "We have no idea of the fine frequency structure of the universe," said Billingham. That's because astronomers typically study the radio sky at bandwidths of 1,000Hz and wider where natural objects are known to radiate. JPL's narrow band sky survey, however, may discover new atomic and molecular lines, as well as map cold dust clouds between the stars. There's always the possibility of finding entirely new phenomena. "Simply detecting a narrow band signal that was natural would be a very exciting event," Edelson observed. "Of course, that would pale into insignificance compared to finding one that was not natural."

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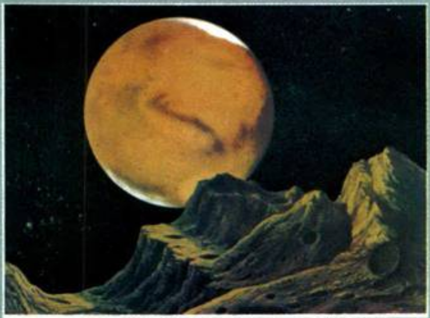

Mars as Seen From Deimos

Actual Poster Size: 17" x 22"

Painted by Victor Costanzo, the red planet Mars and its outer satellite Deimos are set against a real stellar background. To the lower left of Mars is the Hyades, a star cluster in Taurus; at upper right is the constellation Aries. Varnished; suitable for framing. $1.25 each.

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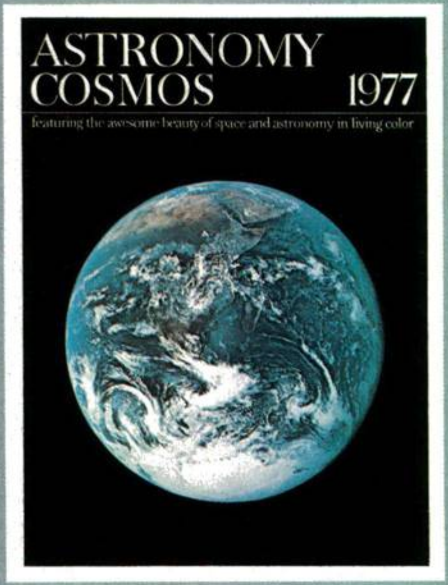
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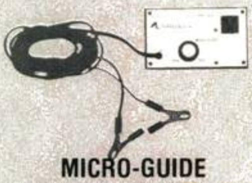

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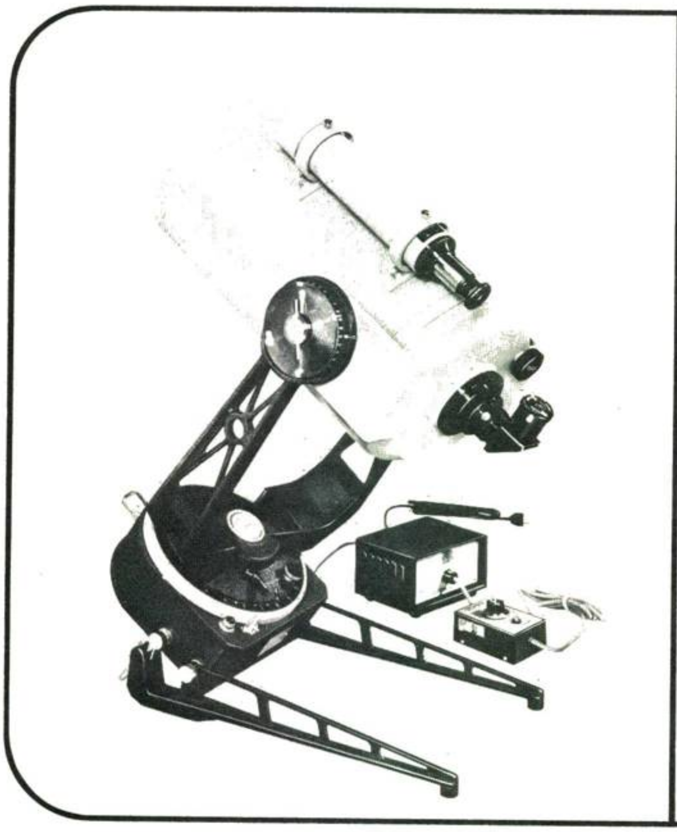

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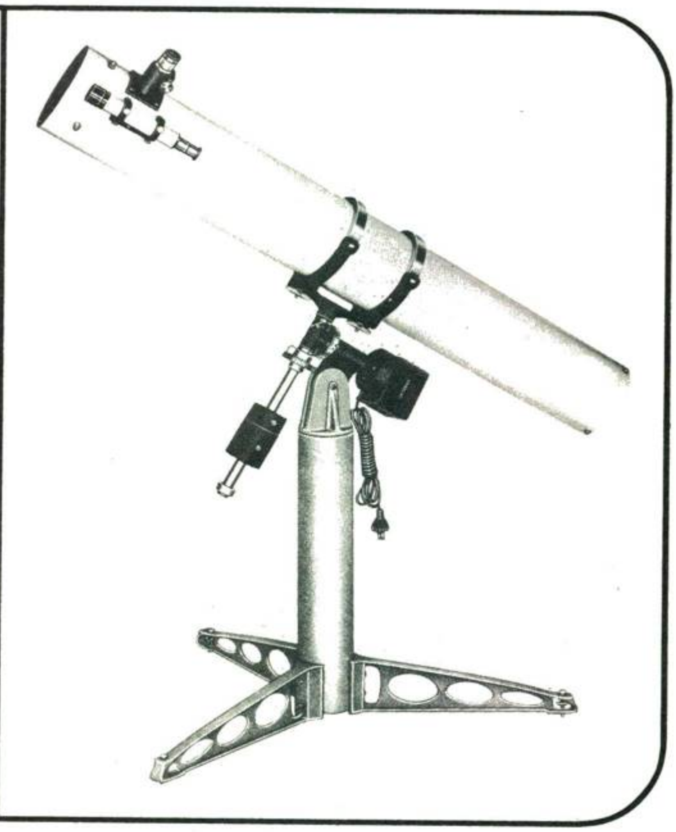

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STAR DOME

MARCH

by
John G. Harmon and James Mullaney

While most of the 88 constellations officially adopted by the International Astronomical Union in 1930 date back to ancient times, there are some which are of more recent vintage. Most of these "new" constellations fill the southern sky, but the north has its share as well. Near the zenith these March nights is an excellent example: the somewhat obscure constellation Lynx.

The brightest star in the constellation is Alpha Lyncis, following the pattern used by Bayer in 1603 in his **Uranometria**. Alpha, however, is only a third magnitude star! A fainter fourth magnitude star, which Ptolemy had earlier ascribed to Ursa Major, is called Alsciaukat, meaning a "thorn" in Arabic.

This is not to say, however, that the rest of the stars are unnamed. Almost every star brighter than 10th magnitude has a name; in fact, usually there are several of them! These names are composed of numbers rather than letters. The numbers appear in star catalogs, some of which are the earliest astronomical records.

The first major star catalog was Ptolemy's **Almagest** of 138 A.D., which listed 1,025 bright stars. To compile this list, Ptolemy used a catalog made by Hipparchus some 266 years earlier. Unfortunately, only fragments of Hipparchus' original list still exist. In preparing the **Almagest**, Ptolemy corrected the original position given for the stars to account for the precession of the equinoxes.

This process was repeated many times by others during the Middle Ages. Estimates of the stars' magnitudes were added by Persian astronomer, Al-Sufi in 964 A.D. Ulugh Begh, the grandson of Tamerlane the Great, refined the positions given for the stars with his own observations around 1437 A.D., as did Tycho Brahe in 1580, and Edmund Halley in 1678. The catalog was expanded to include about 1,600 stars by Hevelius in 1690. It was in this list that Lynx made its first appearance.

The early catalogs were limited to naked eye stars because they were compiled prior to the invention of the telescope. Because of this, they were generally only of historical value. The first catalog produced by using a telescope was Flamsteed's **Historia Coelestis Britannica**, published in 1729 (see Star Dome, December 1977). In this catalog Alsciaukat is listed as Fl 31 Lyncis, and Alpha is called 40 Lyncis.

Since Flamsteed's time, the number of star catalogs has grown. Some, like Flamsteed's, are basic lists of stars, usually down to some limiting magnitude. Typical of these are survey catalogs such as Friedrich Wilhelm August Argelander's **Bonner Durchmusterung**, or **BD** for short. The name implies a careful examination or "scanning through" of the heavens with the 72mm (2.8 inch) telescope at Bonn Observatory. Argelander, and later his student Schoenfeld, tried to list all stars brighter than 9.5 magnitude, from the north celestial pole down to declination -22 degrees. The resulting catalog, published in 1862, contains about 453,000 stars grouped in zones of one degree of declination in width, starting from the pole. Within each zone, the stars are listed in order of increasing right ascension. The catalog then gives the position of the star and its magnitude. Using the two brightest stars of Lynx once again as examples, Alsciaukat (which has a declination of +43 degrees 31 minutes) is listed as BD +43°1815 (the 1,815th entry in the +43 degree list). Alpha, being farther south, is BD +34°1979, the 1,979th entry in the +34 degree list.

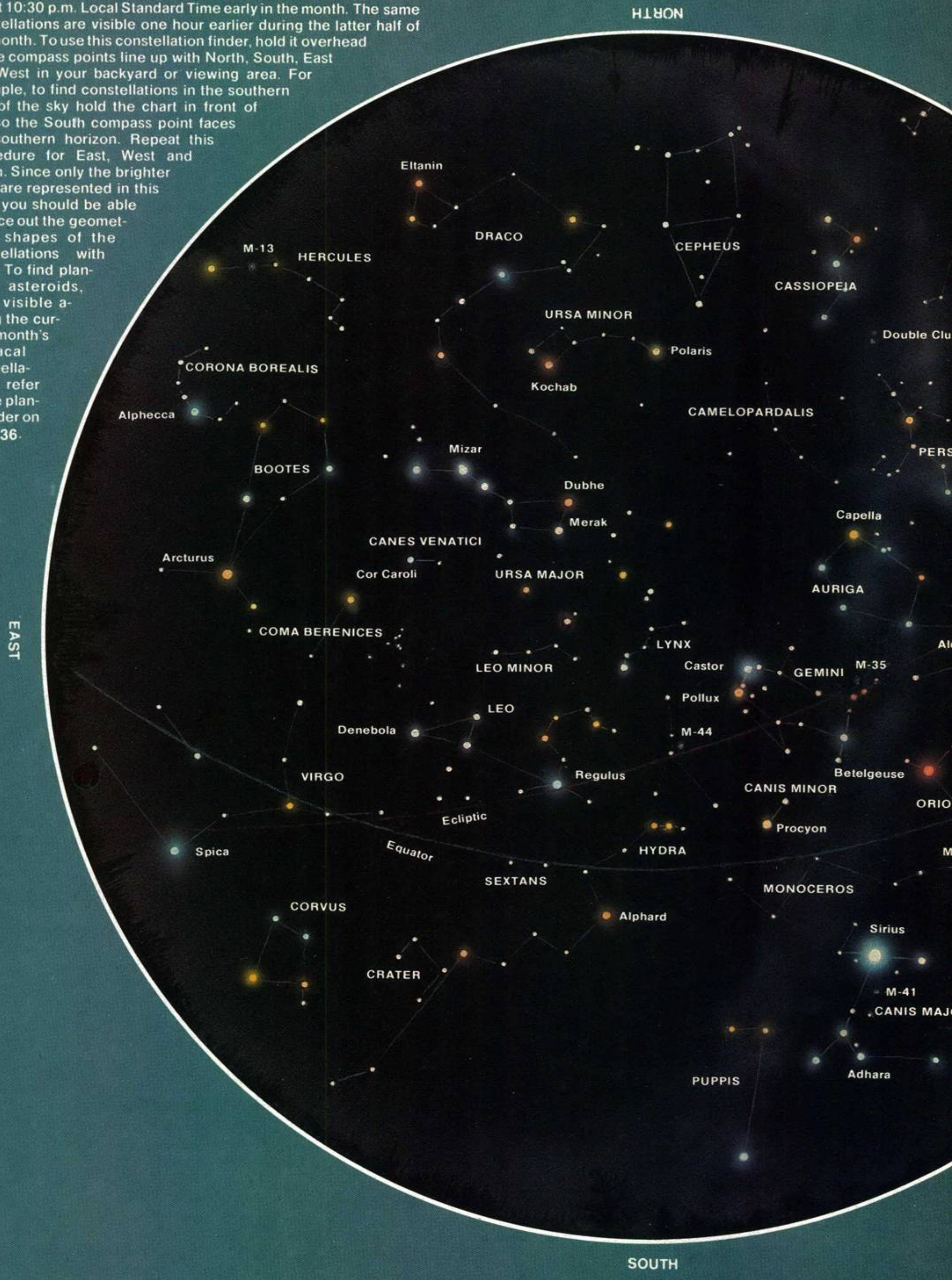
This catalog was later extended to the south celestial pole by observations made from Cordoba, Argentina. This list, known as the **Cordoba Durchmusterung** or **CoD**, contains about 580,000 stars down to 10th magnitude. Another southern extension which lists about 455,000 stars is the **CPD** or **Cape Photographic Durchmusterung**.

These survey catalogs are of primary interest to the professional observer. You will probably find one of the several catalogs which list only the brighter stars to be more useful in your observations. Typical of these are the **Yale Bright Star Catalog** or **BS**, and the **Boss General Catalog** or **GC**. The **GC** should not be confused with Dreyer's **New General Catalogue**, the **NGC**, which lists nebulae, clusters and galaxies rather than stars. The **GC** includes 33,342 stars down to about seventh magnitude. The shorter **BS** has a limiting magnitude of 6.5. Since both of our "named" stars in Lynx are brighter than these limits, they are contained in both catalogs. Alsciaukat is BS 3275 and GC 11401 respectively, while Alpha is designated BS 3705 and GC 12880 – again, the number simply being its place on the list.

The **GC** is also an example of what is known as a *fundamental catalog*. In these, the positions of the stars are determined with extreme accuracy. Fundamental star catalogs provide points of reference for the positions of the fainter stars in the other catalogs. The first of these lists was the **Fundamental Katalog**, or **FK**, of 1879. An improved third edition, the **FK3**, lists Alsciaukat as FK3 314, and Alpha as FK3 452.

These numerical "names" are for the most part limited to catalogs, and with the exception of Flamsteed numbers do not appear on star maps. But on most maps, in addition to Flamsteed

This Star Dome rendering approximates the sky as it appears at about 10:30 p.m. Local Standard Time early in the month. The same constellations are visible one hour earlier during the latter half of the month. To use this constellation finder, hold it overhead so the compass points line up with North, South, East and West in your backyard or viewing area. For example, to find constellations in the southern part of the sky hold the chart in front of you so the South compass point faces the southern horizon. Repeat this procedure for East, West and North. Since only the brighter stars are represented in this map, you should be able to trace out the geometrical shapes of the constellations with ease. To find planets, asteroids, etc., visible among the current month's zodiacal constellations, refer to the planet finder on page **36**.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CEPHEUS
M-13
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Polaris
CORONA BOREALIS
Kochab
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Dubhe
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Cor Caroli
URSA MAJOR
AURIGA
EAST
COMA BERENICES
LYNX
Al
LEO MINOR
Castor
GEMINI
M-35
Pollux
LEO
Denebola
M-44
VIRGO
Regulus
Betelgeuse
CANIS MINOR
ORIO
Ecliptic
Procyon
Spica
Equator
HYDRA
M
SEXTANS
MONOCEROS
CORVUS
Alphard
Sirius
CRATER
M-41
CANIS MAJ
Adhara
PUPPIS
SOUTH

Map Centered on 40° North Latitude

ANDROMEDA
TRIANGULUM
ARIES
Algol
S
Pleiades
CETUS
Hyades
aran
TAURUS
WEST
Bellatrix
ERIDANUS
Rigel
LEPUS
COLUMBA

Map by Adolf Schaller

and Greek letter designations, you'll find a few stars which are marked by one or two English letters. The star RR Lyncis is one such star.

This particular nomenclature indicates a variable star. These stars which change in brightness are designated in a rather unusual way. The first variable found in a constellation is designated by the letter R, the next by S, and so on to Z for the ninth variable discovered. For number 10, you go back to R, but double letters are used as in RR Lyncis. The next would be RS, then RT, and so on to RZ. Having exhausted the Rs, you start with SS, and then use ST through SZ, and continue in this manner until you reach ZZ. You then jump to the front of the alphabet, starting with AA through AZ, BB to BZ, and so on. An exception is any combination beginning with the letter J, as it might be confused with I. This backward arrangement ends with QZ, since the next combination would be RR which you've already used. By this method, 334 variables can be named. If more are found, they are designated by the letter V and a number, starting with V335!

Variable stars are also listed in the catalogs we mentioned. RR Lyncis is also known as BD +56°1125, BS 2291, GC 8281, and HD 44691. The last designation is from the **Henry Draper Catalog**, a listing which includes spectral classifications of stars down to magnitude 8.5.

This is just a sample of the many catalogs that exist. Others — more specialized — include lists devoted to double stars, variable stars, nearby stars, novae and supernovae, to name just a few.

Close-Up

Lynx Region

Despite ranking a respectable 28th in size among the 88 constellations, Lynx is perhaps the most somber looking and neglected of all the northern star groups. It lies between 6 and 10 hours of right ascension, filling the lonely expanse of sky between Auriga and Ursa Major.

Olcott considered Lynx a "little asterism", and although noting that it is rich in double stars, he included none of its objects in his classic observing guide. Barns called this group "a scattered constellation with few conspicuous units".

The best assessment of this month's region is that given us by Webb: "A troublesome constellation, excepting with an equatorial mounting, as there are few conspicuous leaders among a number of tolerably considerable stars, which are puzzling in the finder. The beauty of its pairs will, however, reward a persevering observer." He listed over 50 double and multiple stars here suitable for smaller instruments; some of the more interesting are given in our table and described below.

The brightest star in Lynx shines at barely third magnitude — Alpha (α) Lyncis, an orange giant of spectral class M0 some 180 light-years distant from us. As seen in the telescope, it has several faint attendants in the field that have blue or violet casts to them.

Espin (one of Webb's fellow observers) pointed out the presence here of what might be called an "asterism within an asterism" if we accept Olcott's term for Lynx. This is a group of five stars in a line, together with fainter ones, just west and south of 34 Lyncis near right ascension 8 hours 40 minutes and declination +45 degrees. Otherwise this month's region is devoid of any clusters or nebulae of interest to the telescopist, and hosts only one prominent galaxy (NGC-2683, described below). Yet Lynx still has its attractions and certainly deserves much more attention from observers than it has ever been accorded.

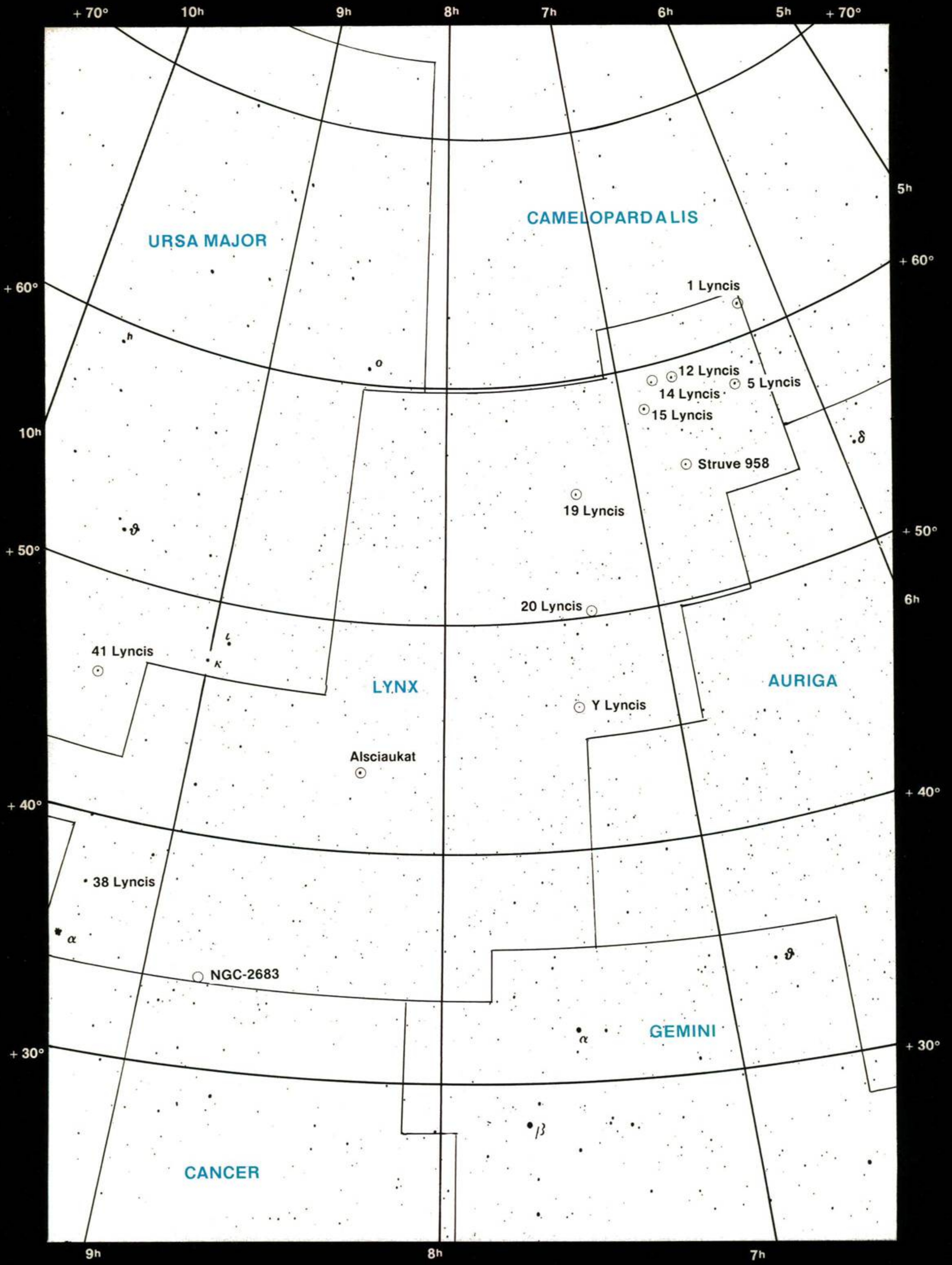
To bring home this point, we provide brief descriptions of all 12 entries in our table of selected objects this month. The interest and variety of the wonders to be found even in an avoided area of the sky like Lynx may well surprise you! With the exception of the two variable stars R and Y Lyncis, and the galaxy NGC-2683, all these targets are visible to the unaided eye and can be spotted directly with careful attention to a good star atlas.

12 Lyncis

One of the real telescopic attractions of this month's region is the stunning triple star system, 12 Lyncis. This neglected showpiece consists of a fifth magnitude primary with a sixth magnitude companion, currently 1.7 seconds of arc away near position angle 90 degrees (due east). The two suns form a slow binary whose orbital period is calculated to be about 700 years.

Adding to the beauty of the scene is an eighth magnitude star at eight seconds distance and position angle 308 degrees (to the northwest). Some sources consider this object as bright as 7.4 magnitude; others rate it a full magnitude fainter. All three stars seem to be moving through space together as a family and are almost exactly the same distance from us as Alpha Lyncis.

The close pair is considered a test for a three inch scope, and all three components are well seen in a four inch at 100 power or more in good seeing (image steadiness). In medium


+ 70°
10h
9h
8h
7h
6h
5h
+ 70°
5h
+ 60°
+ 60°
10h
+ 50°
+ 50°
6h
+ 40°
+ 40°
+ 30°
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URSA MAJOR
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κ
LYNX
AURIGA
Y Lyncis
Alsciaukat
38 Lyncis
α
ϑ
NGC-2683
GEMINI
α
β
CANCER
9h
8h
7h

Photograph by Brad Wallis and Robert Provin apertures 12 Lyncis is quite lovely and takes magnification well, as our drawing with an eight inch reflector at 400 power suggests.

Pickering included this object under his category, "Finest Multiple Stars" in his 1917 roster of the sky's best sights, compiled with an 11 inch refractor. Back then the close duo was separated by two seconds in position angle 118 degrees. Barns called 12 Lyncis a "superb triple" as seen in his 10 inch reflector.

In 1854, at a separation of about 1.5 seconds (position angle 154 degrees), Webb found that he could elongate the image at 80 power and divide it at times with 144 diameters. He noted the close pair as both yellowish-white in hue and the third star ruddy. Smyth gave them as white, ruddy and bluish in order of brightness, while other observers recorded two greenish-white and one bluish here. How do you see them through your telescope?

19 Lyncis

Another attractive trio for small scopes is 19 Lyncis. Here we find stars of 5.6, 6.5 and 8th magnitude at roomy separations of 15 and 215 seconds of arc. The closer pair again forms a long period binary, with the third star apparently along for the ride. The primary is also a close unresolved spectroscopic double with a period of only 2.3 days.

This object is a fine sight even in a two inch refractor at 30 power. The tints here in order of brightness seem to be white, blue and lilac. Smyth logged them as "white, two plum colored" in his six inch refractor. Few other observers have ever ventured into this forbidding region to leave their impressions; why not try noting yours?

41 Lyncis

Still another object that could be considered a triple star, but is usually regarded as a course double, is 41 Lyncis. Its 5.6 and 7.8 magnitude components are separated by some 80 seconds, or more than a minute of arc — too wide for inclusion in many lists, but the Struves and Webb (among others) recognized it as a bona fide pair.

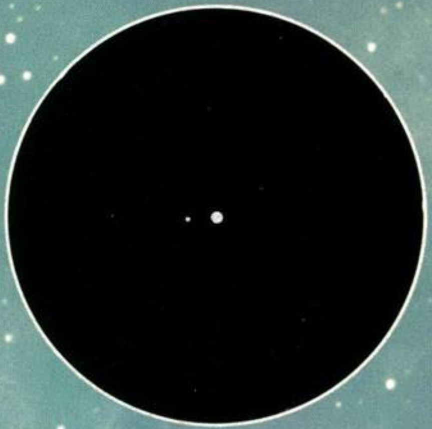
Webb pointed out the presence of a 10th magnitude star in the field with the wide duo forming a triangle, making 41 Lyncis a very weak apparent triple system in the telescope. He noted the colors of the brighter stars as deep yellow and lilac, while another impression was yellow and white or azure. All three objects are readily seen in a six inch reflector at 50 power.

38 Lyncis

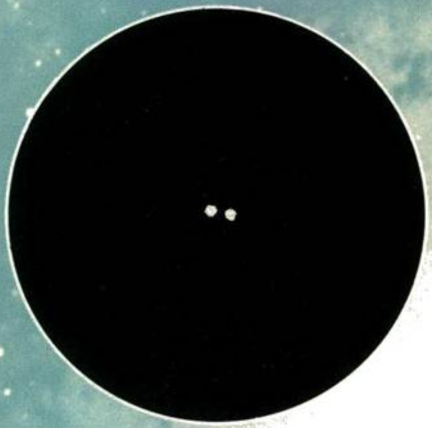
Turning our attention now to some of this region's close double stars, we present, in order of decreasing separation, three binaries as a challenge for those of you who enjoy splitting tight pairs. Depending on the state of the atmosphere (remember those blustery March skies!), telescopic aperture and optical quality, magnification employed and training of the eye, you may or may not find these resolved in your scope.

Easiest and most attractive of our offerings is 38 Lyncis, a stunning pair of fourth and sixth magnitude suns presently just under three seconds apart. The companion is moving slowly

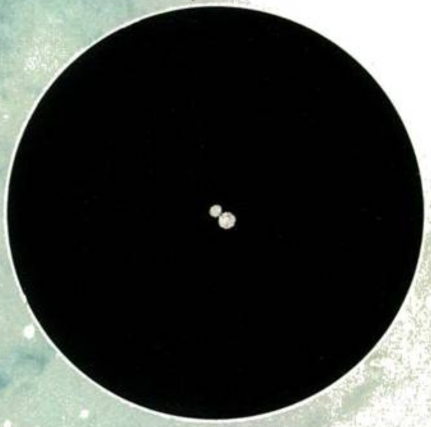
Double and multiple stars never fail to enchant telescopic observers with subtle contrasting colors and the sheer thrill of seeing two or more stars where the eye sees only one. Lynx is a fine hunting ground for these objects; easy ones as well as difficult ones are tucked away in this half-forgotten constellation. Drawings by James Mullaney.



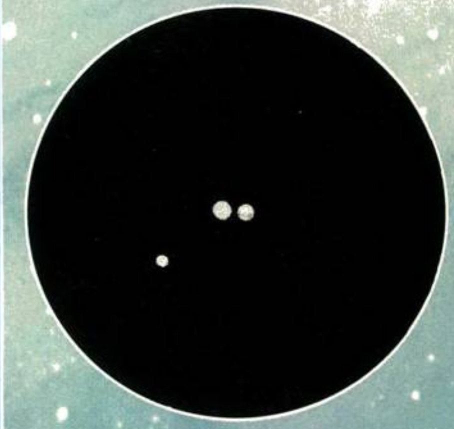
80x 5 Lyncis



160x Σ 958



160x 38 Lyncis



400x 12 Lyncis

Selected Objects — Lynx Region

Object	Type	Mag.	Size/ Sep.	R.A. (1950)	Dec.
* 5 Lyncis	★2	5.5,8.2	96"	06^h22^m	+58°27'
* 12 Lyncis	★3	5.4,6.2,8.0	1.7",8"	06^h42^m	+59°30'
* Struve 958	★2	6.3,6.3	5"	06^h44^m	+55°46'
* 14 Lyncis	★2	5.9,7.1	0.3"	06^h49^m	+59°31'
* 15 Lyncis	★2	4.9,6.1	0.9"	06^h53^m	+58°29'
* R Lyncis	V:379^d	7.2-14.0	—	06^h57^m	+55°24'
* 19 Lyncis	★3	5.6,6.5,8.0	15",215"	07^h19^m	+55°23'
* 20 Lyncis	★2	6.6,6.8	15"	07^h19^m	+50°16'
* Y Lyncis	V:110^d	6.9-7.4	—	07^h25^m	+46°06'
* NGC-2683	SG	9.6	8'x1'	08^h50^m	+33°38'
* 38 Lyncis	★2	4.0,6.0	3"	09^h16^m	+37°01'
* 41 Lyncis	★2	5.6,7.8	80"	09^h25^m	+45°49'

* Detailed in Close-Up

★2 = Double Star
★3 = Triple Star
V:#^{d} = Variable Star, Period
SG = Spiral Galaxy
Mag. = Magnitude
Sep. = Separation

clockwise on the sky (its position angle is decreasing) with respect to the primary, and now lies near 230 degrees. A three inch refractor at 150 power shows their images just touching each other on a typical night. Larger apertures widen the gap for a more comfortable view, as indicated in our sketch with an eight inch reflector at 160 power.

Among the colors given for the two stars are silvery-white and lilac (Smyth) and yellowish-white and tawny (Webb). Greenish-white and blue, as well as both yellow, have also been reported. Barns made no mention of tints in his description, but instead left us with the puzzling remark "vivid stellar horseshoe" for this object. He could have been referring to the surrounding star pattern; can you confirm this from your own observations?

15 Lyncis

Next in order of difficulty is 15 Lyncis, a fifth and sixth magnitude duo now just under one second in separation. On a steady night, three and four inch scopes at high magnification elongate this double into a pear shaped image and suggest actual resolution, but at least five or six inches of aperture are needed for a clean split. Yellow and gold have been given for its tints, but few have passed by this way to verify that impression.

14 Lyncis

Should you be successful with the last two pairs, you're ready to tackle our final challenge. This is 14 Lyncis, whose sixth and seventh magnitude components are now near 1/3 second apart — beyond the limit of all but the widest aperture small telescopes.

This difficult binary has a period reckoned at 614 years and has been closing for well over a century. In 1833 the stars were one second apart in position angle 50 degrees; in 1875 they were 0.7 second at 64 degrees; in 1910, 0.5 second and 88 degrees. By 1954, the gap between stars had decreased to 0.3 and the position angle increased dramatically to 215 degrees. Such a rapid change in angle is explained by the fact that the components had reached periastron (closest approach to each other) a year or so before and were therefore moving at their highest orbital velocity.

The separation of 14 Lyncis should now be increasing and slowly make this pair an easier object. Unfortunately, there are *extremely* few current observations available; the best guess is that the stars are about 1/3 second in apparent separation. At least a 10 or 12 inch scope will be needed to show them as other than a single blended image. Even if 14 isn't resolved in your telescope now, it should be fun to watch this duo open up in coming years!

In the early 1800s, when 14 Lyncis was within reach of medium size telescopes, striking hues were reported for its two suns — golden yellow for the primary and purple or green for the companion. (Their actual spectral types are G0 and A2, respectively.) Clearly, here is a stellar pair that holds much promise for the visual observer in the future! Start your explorations tonight.

20 Lyncis

Should tightly bound pairs like those above leave you disappointed, compensation can be found in our next few selections — all of which are easy and attractive doubles for a small telescope. The nearly matched silvery-white glow from the gems making up 20 Lyncis is sure to please your visual senses. Its 6.6 and 6.8 magnitude components are 15 seconds apart and striking even in a two inch refractor at just 30 power. Barns noted that the sky about this object was the "most requiting region of this odd and rather featureless constellation". Do you agree?

Struve 958

One of the many entries from the double star catalogs of the Struves to be found in Lynx is Sigma 958 (also known as Struve 958) — perfectly matched 6.3 magnitude twin suns a cozy five seconds apart. They form a common proper motion pair drifting the ocean of night together; an unseen spectroscopic companion is also present.

Our drawing shows this object in an eight inch reflector at 160 power, but it's much more stunning as aperture and magnification *decrease*. In a three inch refractor at 45 power, Sigma 958 looks like some delicate piece of golden cosmic jewelry set against black velvet!

5 Lyncis

For those who like some magnitude contrast in their doubles as well as color, we suggest taking a look at 5 Lyncis. This optical pair consists of a fifth magnitude orange giant sun teamed with a much fainter eighth magnitude companion 96 seconds to the west, as shown in our drawing with an eight inch reflector at 80 power. Barns described the K5 primary as "a pendant ruby"!

R and Y Lyncis

Our final stellar offerings in Lynx are two ruddy pulsating variable stars. Brightest is Y Lyncis, situated midway between the stars 16 and 25 Lyncis and readily visible in a finder throughout its cycle. This gem is classified as semiregular in behavior and varies from 6.9 to 7.4 magnitude in a period of about 110 days. Of spectral class M5, it has a distinct red hue in the telescope.

The other variable is R Lyncis, located roughly midway between the doubles 19 Lyncis and Sigma 958. At maximum light, it glows near seventh magnitude and is easily seen in a finder; but at minimum it drops to nearly 14th magnitude and takes a good eight inch telescope! This restless sun is a long period variable of the Mira Ceti type whose complete cycle requires some 379 days. It is next expected at peak brightness this spring on May 25, according to the American Association of Variable Star Observers. R Lyncis is a member of spectral class type S and, like Y Lyncis, has a distinctive deep red hue throughout its entire range.

NGC-2683

We conclude our survey of this month's region by examining the only prominent galaxy — and, indeed, the only real deep sky wonder — to be found here. This is NGC-2683, a 9.6 magnitude spiral measuring a cigar shaped eight by one minute in size. To find it, sweep with a low power eyepiece on the telescope about a degree south and five degrees west of Alpha Lyncis — just above a naked eye group of stars at the Lynx-Cancer border.

This remote star city was discovered by Sir William Herschel and is designated H-I^{200} — the 200th entry in his Class I (bright nebulae). It is among the brightest of his many finds and is more impressive than many of Messier's galaxies. Yet it seems little known to observers, both past and present.

Webb's description of NGC-2683 is about all we have to guide us in our scrutiny of this object, aside from that of the NGC itself. Including it under Leo Minor rather than Lynx, he noted: "Herschel calls this a very beautiful object . . . Smyth saw a splendid center. Scarcely worth the search with 3.7 inch (refractor), but in a very fine district . . . ."

The NGC's coded account reads: vB, vL, vmE 39°, gmbM — which translated means "very bright, very large, very much extended in position angle 39 degrees, gradually much brighter in the middle".

Good modern descriptions of all deep sky objects are needed today; this is especially true for neglected or overlooked specimens like NGC-2683. Apparently the somber aspect of its host constellation has relegated this minor showpiece among galaxies to an undeserved obscurity. Why not look it over the next dark transparent night with your telescope and help fill such gaps in the observational record? In so doing (yes, even here in Lynx!), you will discover — as Lord Dunsany remarked in his **The Laughter of the Gods** — that "A man is a small thing and the night is very large and full of wonders."

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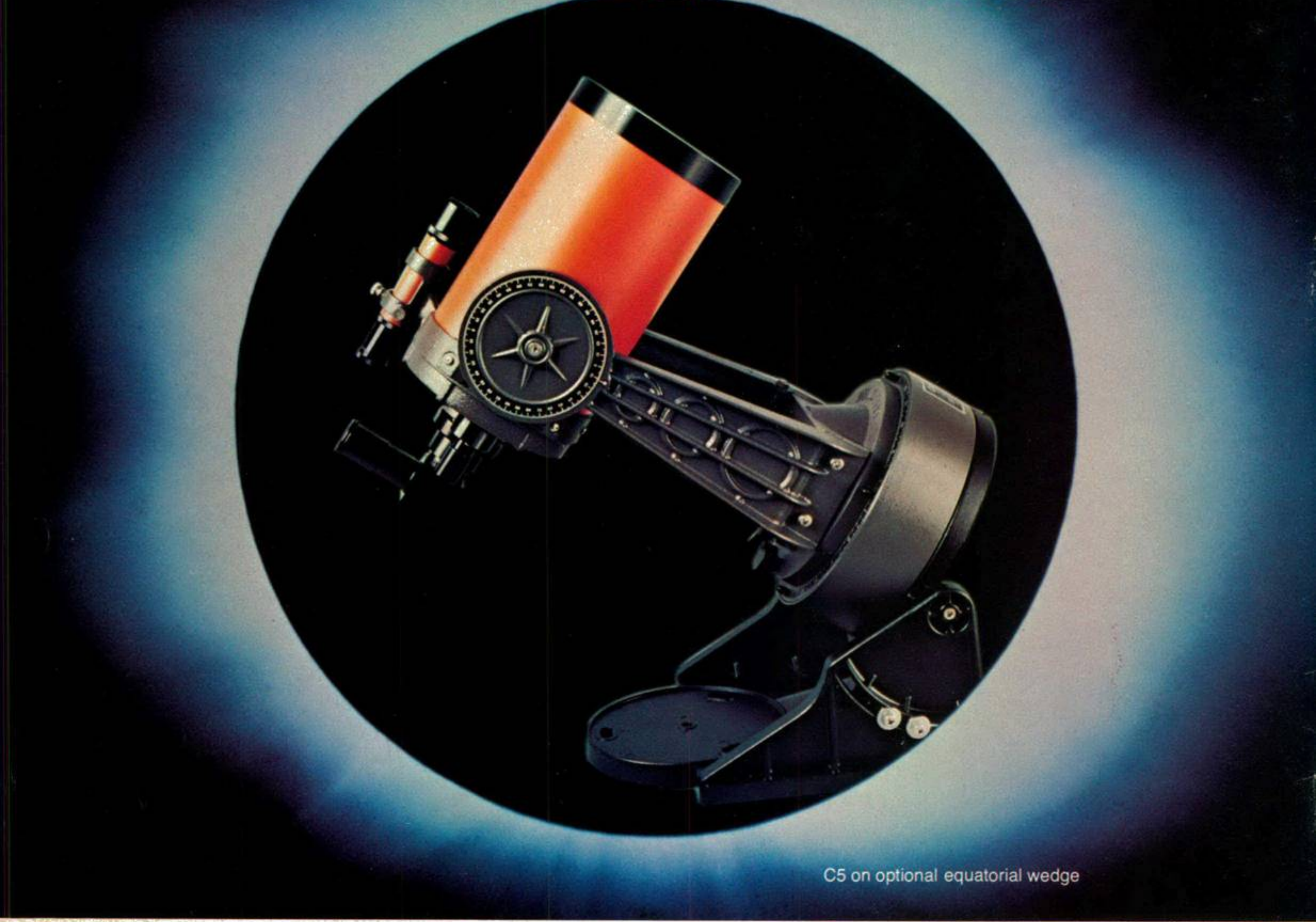

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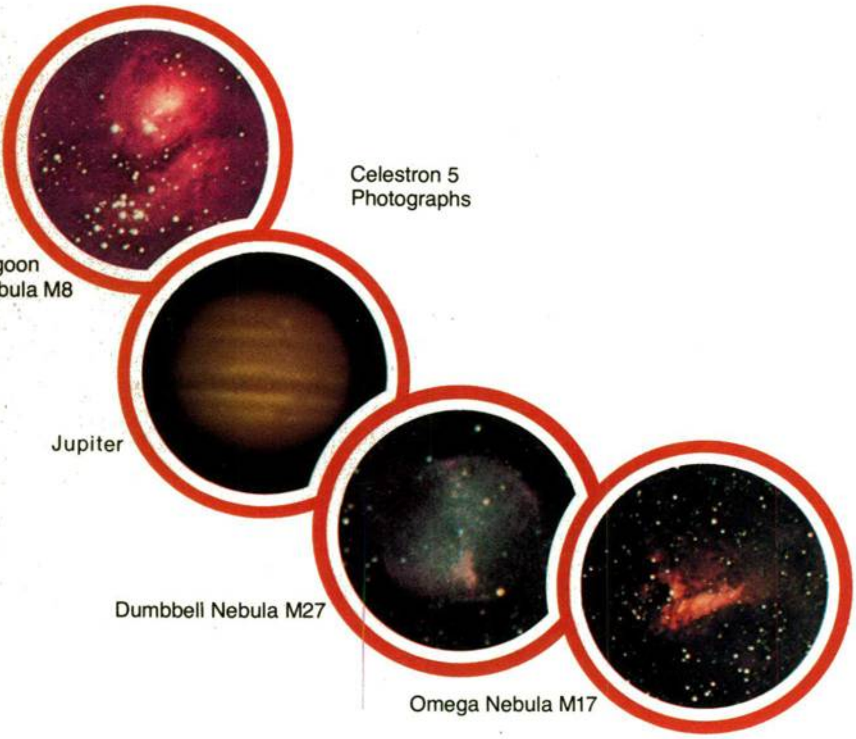

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